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SPRINKLER IRRIGATION

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SPRINKLER IRRIGATION

is sometimes the only method of applying water that can be used successfully. On some farms it has replaced the furrow or flood method of irrigation. On others, surface methods may be more satisfactory.

Each farm has its own particular set of conditions, its own particular problems. The general advantages and limitations of sprinkler systems must be thought of in relation to the conditions of soil, terrain, crops, and total operation of your own farm. You will find a discussion of the conditions that call for a sprinkler system, plus an analysis of the pros and cons, on pages 4-9

Sprinkler systems may be stationary, portable, or semiportable. The systems and the various units of which they are composed are described on—
pages 9-18

Good design and proper operation are essential to successful sprinkler irrigation, as they are to any other method. The points to consider, together with guides for selecting equipment and planning layout, are outlined on pages 18-36

Special aspects—the application of fertilizers through the sprinkler system and the problem of corrosion—are discussed on pages 37-40

Cost is an important factor. Sprinkling is usually expensive, but often it may be cheaper than other methods. The initial investment and annual operation costs should be estimated carefully. For guidance in calculating total expenses, see—
pages 40-43



Ask these questions

1. What are the advantages and limitations of sprinkling in relation to your farm? ?
2. What type of system, what capacity, what method of operation do the conditions on your farm call for? ?
3. What would such a system cost to install, operate, and maintain? ?
4. How does the estimated cost of sprinkling compare with other methods of irrigation? ?
5. If the cost of sprinkling is greater, do the advantages justify the increased cost? ?

This circular cannot give detailed answers to these questions for every farmer. It does, however, tell how you can arrive at the answers for your own situation. The information contained here will help you in making decisions—first, whether or not to adopt the sprinkler system; second, how to proceed if you do decide on a sprinkler installation.

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SPRINKLER SYSTEMS—WHEN AND WHY

A satisfactory irrigation system applies water to the soil in the amounts needed to maintain an adequate and constant supply of soil moisture in a major portion of the plants' root zone. It does so at reasonable cost, with minimum waste of water, land, power, and labor.

Sprinkling is the best method of irrigation in many cases, though not all. In some situations conditions of soil or terrain, or the crops to be grown, may make surface methods more desirable. Since no two farms have the same requirements, it is necessary to consider all the facts for a particular farm to decide which type of irrigation system will be most satisfactory.

Most sprinkler systems are alike in that they carry the water under pressure through pipe and discharge it through sprinklers, nozzles, or perforations in the pipe. Among sprinkler systems, however, there are a number of variations or adaptations to meet the special requirements of a particular farm.

No two farms have exactly the same conditions. Bear in mind that *the best*

system for a particular farm is the one that best meets the conditions on that farm.

Field operation of sprinkler systems has established fairly well their general advantages and limitations. Weigh these carefully before you adopt a system.

When is a sprinkler system desirable?

Assuming that there is land available for growing irrigated crops, a sprinkler system may be desirable in any one of the following situations:

New land is to be developed for irrigation.

The topography is rolling or rough.

Soil conditions vary.

The present method of irrigation involves certain difficulties and the irrigation efficiency is poor.

The crops to be grown require frequent light irrigations.

Problems of seed germination have been encountered.

The flow of water is not large enough to permit efficient irrigation by surface methods.

Sprinkler systems are often desirable on uneven land . . .



Other problems may exist, unique to a particular farm, and these may suggest the use of a sprinkler system.

Sprinkler systems have these advantages . . .

In general, a sprinkler system can be used satisfactorily under most conditions, provided enough water is applied at proper rates to meet the crop and soil requirements.

Sprinkling is particularly adapted for use on land with rough, irregular features. It reduces the cost of, or eliminates, expensive land grading and preparation often needed for surface methods.

In some areas where excessive land grading can be detrimental, sprinkling has a definite advantage. Furthermore, shallow hardpans, a limited depth of tillable soil, or organic soil types such as peats may restrict, if not completely prevent, grading operations.

Good water control is possible with sprinkling. With proper design and operation, sprinkling achieves nearly uniform water application even on irregular terrain or under variable soil conditions. In some areas, especially on pervious soils with sand or gravel subsoils, much of the water applied by surface methods may be lost by deep percolation unless the system is carefully designed and operated to minimize such losses. The

same soils may be sprinkled without excessive waste.

If the water-holding capacity of the soil is very low, sprinklers can provide the frequent irrigations that are necessary at a saving in both water and labor. Similar saving is also possible in situations where the crop needs only a single light irrigation during the year.

In some areas of high water table, sprinkling has this advantage over surface methods—it can apply the proper depth of water to wet the soil without raising the water table.

In a few places farmers have had difficulty in irrigating deep-rooted crops on clay-type soils by flooding because sinkholes develop in the fields. Large cracks occur as the soil dries. During irrigations water enters these cracks, washes away the soil, and enlarges the cracks into sizable cavities. In addition, they become a hazard to harvesting or cultivating equipment. Sprinklers prevent the accumulation of large amounts of water on the soil surface and the continued development of the holes.

Land slopes are so steep in some parts of California that efficient surface irrigation is difficult or virtually impossible, and surface washing causes excessive soil erosion. Sprinkling can prevent soil erosion and still provide the required amount of water. The planting of a per-

Courtesy Ames Company, San Francisco . . . or on widely spaced row crops . . .





... in vineyards ...

manent cover crop in orchards, combined with the use of sprinklers, helps reduce soil loss.

Often, only light irrigations are needed to germinate seed. These can usually be applied more efficiently by sprinklers than by furrow irrigation. Lateral movement of water from furrows into the seed bed may be limited or nonuniform, resulting in poor stands. Sprinklers also help to leach salts from the surface, creating a more favorable environment for seed germination. The exact placement of fertilizers in the beds may not be as critical where sprinklers are used as it is with furrow irrigation.

... or in orchards.



Many orchard, field, and vegetable crops have been irrigated successfully by sprinklers. However, experience with some crops under the variety of field conditions that exist is lacking. Certain changes in cultural practices may be necessary when sprinklers are used; in some cases furrows and raised beds are eliminated, thus reducing labor costs.

On widely spaced row crops sprinklers can provide more uniform application of water over the entire soil area. This is true on soils where lateral movement of moisture from the furrow into the crop row is slow, and the young plants often suffer before enough soil moisture reaches the root zone.

In the seed production of some row crops and crops with tall stalks, such as corn and pole beans, sprinklers are satisfactory during the early part of the growing season. To start these crops short sprinkler risers are often used, their length being gradually increased as the crop matures.

Certain advantages have been realized in the irrigation of field crops. For example, borders or levees used in growing alfalfa can be eliminated. This lowers the land-preparation costs, facilitates harvesting, and may reduce the hours of mowing and raking operations.

Irrigation by sprinklers has advantages in areas of sandy or shallow soils or where a hilly terrain makes it difficult to secure uniform water application by other methods.

In orchards, sprinkling eliminates the need of constructing ridges, levees, or furrows between the trees and allows the soil surface to remain smooth throughout the season. The reduction in soil manipulation may contribute to better water penetration, reduce the dust problem, and facilitate mechanical harvesting of certain nut crops.

Insect control is often listed among the advantages of sprinkler systems, although little experimental work has been

done from which definite conclusions can be drawn. Many growers report, however, that such pests as aphids, thrips, and red spiders are less troublesome on some crops that are sprinkler irrigated. Under some conditions sprinkling may reduce certain pests, particularly if it is started early in the season. The explanation for this is that the environment is probably less favorable for the insects. In general, leaf-feeding insects are not controlled, for they crawl under the leaves during the irrigation. Certain insecticides can be applied through a sprinkler system, providing the material is relatively soluble and noncorrosive. Also, it should be injected into the system near the end of each irrigation set; otherwise it may be washed off. Although a sprinkler system may aid in reducing insects, it should not be considered a substitute for an adequate insect control program.

A sprinkler system can be designed to operate effectively with a small rate of flow. This may be a distinct advantage on a small farm with a limited water supply, for in many places the volume of water from surface supplies or a well is not great enough for other methods of irrigation.

Sprinkler systems can eliminate many field ditches and so permit the planting of almost the entire acreage. Typical irrigated farms have from 2 to 5 per cent of the acreage in ditches. Eliminating ditches may in turn lessen the weed problem and allow cultivation in large blocks. Ditch seepage and evaporation are also reduced or eliminated.

Present-day sprinkler system equipment, including the appurtenances, is readily adapted to various field conditions. The orientation and arrangement of pipelines and sprinklers can be altered to some extent to meet changing field requirements. Flexibility in operation is an advantage, but each change must be carefully studied, considering all of the factors involved.

Some liquid or soluble fertilizers can be applied through sprinklers. When they are distributed evenly by a properly designed system, certain advantages are realized: (1) the fertilizer is distributed over the entire soil mass; (2) a saving may result from eliminating machine application and cultivation required to work dry fertilizers into the soil. A further saving may be accomplished when both irrigation and fertilizer distribution can take place at the same time. However, poor design and operation of the system will result in nonuniform fertilizer application.

There is no general rule regarding the fertilizers that can and those that cannot be applied through sprinklers. Some are corrosive. Others may not dissolve sufficiently and clogging may occur, thereby changing the performance of the system. The use of any one fertilizer will depend on its composition, including impurities, and its corrosive action on all the parts of the sprinkler system. Materials and methods for fertilizer application are discussed on pages 37-39.

The labor involved in assembling and moving a sprinkler system does not require an experienced irrigator. Sprinkling schedules, once worked out, are generally fixed, and all that is necessary is to move the pipe at the proper time.

A relatively high efficiency is usually achieved by sprinkler irrigation, but other factors than efficiency often enter into the picture, too. For example, if a field can be irrigated satisfactorily by either the surface method or a sprinkler system, the over-all irrigation efficiencies of both methods may be equal. With the surface method, however, an irrigator often has to be on the job practically all of the time, and he must be a man who has had considerable experience in managing and controlling water.

... and these limitations

All methods of water application should be designed to give as uniform

application of water as possible. Local conditions will dictate to a large extent the degree to which this may be achieved. A sprinkler system, when correctly designed and operated, can approach fairly uniform distribution, but it still cannot achieve the evenness of rainfall.

One of the biggest difficulties is wind. A carefully planned distribution pattern can be completely distorted by wind. Parts of the area normally covered and wetted may be dry. In some cases operations have been shut down when wind conditions created serious distortions. Certain measures can be taken to relieve this problem—for example, changes in sprinkler nozzles, in the spacing of laterals and sprinklers, and in arrangement. However, changes mean additional equipment and, thus, extra cost. Furthermore, the delay involved in making changes may also cause decreases in crop yields, due to lack of water during critical growing periods. Wind conditions should be considered in the original design of the system to minimize this disadvantage.

More water is lost by evaporation during sprinkling than with surface flood methods. There are two sources of evaporation loss—from the water drops or spray moving through the air, and from the wetted soil and foliage surfaces. The amount lost from the drops and spray is much smaller than that lost from the soil and foliage. The net loss by evaporation will depend on climatic and operating conditions, but it may amount to 5 to 40 per cent of the water applied. In some cases sprinkling only at night will help reduce these losses.

On some soils movement of portable pipe after an irrigation may be a problem. This is true on clay-type soils that drain slowly. It is hard, dirty work to move pipe from one position to another after a heavy application of water, and some puddling of the soil may take place. If the pipe could be left until the soil drained sufficiently, this would not be as

great a problem. However, additional equipment would be required for lateral sets at other locations, thereby increasing the investment in equipment.

To avoid the muddy soil condition, some operators shut down the system and move the laterals before they have run long enough to wet the soil to the required depth. As a result, frequent light applications are necessary. Often, repeated sprinklings mean much more moving of pipe, and hence more operation and labor expense. Also, this increases the amount of water lost by evaporation from the soil surface.

Sprinkling systems cost money. The initial cost, depreciation, maintenance, and repair must be given careful consideration. In general, the initial outlay is relatively high, particularly if a large part of the system is permanent or stationary. A portable system reduces the first cost, but there is additional expense for the labor required to move the pipe. Improvements in the materials used in the construction of the systems are increasing their useful life, but certain field conditions will cause more rapid deterioration than others. For example, if the source of water contains sand, parts of the sprinklers will wear faster. Sand removal devices and wear-resistant materials, such as stainless steel and nylon, however, are being used.

There is little conclusive evidence that sprinkling will either encourage or control plant diseases. Some diseases may occur or spread under the conditions provided by sprinkling because of the relatively high humidity that is created in and around the plants. This is particularly true in low-growing vegetable crops. Climatic conditions may also contribute to an environment that is favorable for blight, fungi, and rot damage. A farmer should be on the lookout for any outbreaks, and in some cases it may be desirable not to operate the system during humid weather.

The effectiveness of insecticides and fungicides may be reduced, unless a coordinated program of sprinkling, spraying, and dusting for insect and disease control is worked out. Dusting and spraying should *follow* an irrigation.

Orchard irrigation by sprinkling presents special problems. Close spacing of trees increases the difficulty of moving the pipe from one setting to the next. When under-tree sprinklers are used, low-hanging branches may interfere with a uniform distribution of water. In a few areas sprinklers are located above the trees. This provides more uniform distribution, but losses due to evaporation and wind interference reduce effectiveness.

Corrosion of sprinkler systems is a problem in a few isolated areas in California. It may be caused by one of several factors or by a combination of them. The sources of difficulty are, principally, the chemical composition of the water and certain electro-chemical relationships between the soil and the material of the system. In some cases certain preventive measures can be used to control this damage.

Distribution of fertilizer through sprinkler systems has certain limitations. Not all fertilizers are soluble enough to be injected into a system. They may sometimes cause moving parts to clog, and this means added maintenance and labor costs. Some fertilizers are corro-

sive. If certain precautions are taken—such as allowing enough time to flush out the system after the fertilizers are injected, or applying protective coatings to the inside of the pipe—damage can be controlled or perhaps eliminated.

During the period of crop blossom set sprinkling should be watched carefully. The impact of the spray may damage or shatter blossoms.

Availability of the water supply may create some problems with sprinkling. In many areas of California, water is delivered to the farmer on a rotation basis by irrigation districts or companies. Deliveries are made at intervals and in relatively large quantities. In some cases to use the water when it is delivered would require an excessive amount of sprinkling equipment. It is generally true that sprinklers are most efficient if they can be operated almost continuously.

All irrigation methods require work, and sprinkling is no exception. Once a carefully planned and designed system is laid out, it will not operate by itself. Occasionally there may be a power failure, the pump may lose suction, or the sprinklers may clog or fail to operate correctly. Therefore, some supervision and maintenance must be continuing functions along with the labor needed to move the pipe. The capabilities and desires of the operator must be considered along with the operational requirements of the system.

SYSTEMS ARE OF MANY DIFFERENT TYPES

Although they have certain basic features in common, sprinkler systems differ widely. They are classified as “portable” when most of the equipment can be moved readily from place to place over the area irrigated; “semi-portable” when only a part of the equipment is moved; “stationary” or “permanent” when all of the equipment is fixed.

Systems may also be classified according to their method of distributing the water. This may be by means of rotating sprinklers, fixed sprinkler heads, nozzle lines, or perforated pipeline.

In California, portable systems using rotating sprinklers outnumber all other agricultural sprinkling systems combined.

Sprinkling is often called “overhead” irrigation. This is not accurate, however—the water does not always issue from an overhead outlet. One true “overhead” system is the kind that discharges water over orchard treetops from outlets attached to high risers; but even in orchards, some sprinklers (called “under-tree,” “low-angle,” or “ground”) distribute the water near the ground.

Different types of outlets do different kinds of work

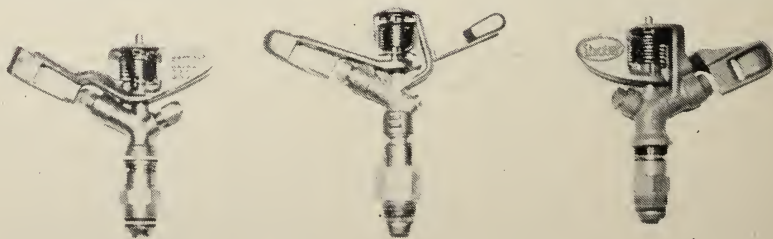
Rotating sprinklers. The majority of agricultural sprinklers are of the rotating type. A wide range of sizes, with discharge capacities of 1 to more than 600 gallons per minute, is available to meet a variety of field conditions. A relatively large area is covered by these sprinklers, depending on the pressure, size of nozzle, and speed of rotation.

There are two general types of rotating sprinklers: The *slow revolving*, which rotates slowly, and the *whirling*, which rotates rapidly. The slow-revolving type is the most common. The speed of rotation varies but ordinarily is from 1 to 2 revolutions per minute. Rotation of the sprinkler is caused by the impact of a lever arm that oscillates in and out of the nozzle jet. The sprinklers used in agricultural practice are designed for two—sometimes one—replaceable nozzles. Interchanging of nozzles provides additional flexibility of operation, as the dis-

charge rate and diameter of coverage can be altered. The angle of the nozzle varies between 7 and 30 degrees. The low angle is used in orchards or in situations where the spray should be kept close to the ground.

The operating pressure is important. Most sprinklers will operate satisfactorily over a range of pressures. However, best results are obtained by maintaining pressures at or above the minimum recommended by the manufacturer for a given size of sprinkler and a given number and size of nozzles. The pressure recommended is usually between 25 and 50 pounds per square inch at the sprinkler. Larger-capacity sprinklers usually require pressures beyond this range. It should be pointed out that although a greater diameter may be obtained by increasing the pressure, this may not produce desirable results. The shape of the distribution pattern will also be affected, and uneven water distribution may result.

Remember, too, that one sprinkler will not give uniform distribution over the entire area of coverage. To obtain fairly uniform coverage, there should be an overlap from an adjacent sprinkler or sprinklers. A 40 per cent overlap is usually considered desirable with square spacing of sprinklers; however, square spacing is seldom used in agricultural practice except on permanent installations. When rectangular spacing is used,



A few of the common slow-revolving type of agricultural sprinkler heads.

which is most common, best results are obtained by spacing the sprinklers about 60 per cent of the wetted diameter one way and from 20 to 60 per cent of the wetted diameter the other way. Under windy conditions (4 miles per hour or more), special planning is necessary, such as closer lateral and sprinkler spacing, laterals placed perpendicular to the wind, use of a single nozzle, or higher operating pressures.

Whirling sprinklers operate at much faster and more constant speeds of rotation than the slow revolving. Rotation is caused by the reaction of the jet of water discharging from the nozzle. The nozzles are attached to a rotating arm at an offset angle. However, if both types are operated with similar capacities and under equal pressures, the whirling sprinkler covers about half the diameter of the slow-rotating type.

Slow-revolving sprinklers have these advantages over the whirling type: (1) they permit the economy of spacing pipe-lines and sprinklers farther apart because of their greater diameter of coverage; (2) slower rates of water application can be obtained, a very desirable feature where soils are not highly porous; (3) slow rotation reduces wear, prolonging the life of the sprinkler.

Fixed heads. Fixed heads are used mainly for lawns, to some extent in avocado and citrus orchards, and in nurseries. Most of these heads have no moving parts. A few have units that rise vertically out of the fixed-head housing when water is being discharged. One other type has rotating nozzles; this is known as the rotary pop-up sprinkler and is used largely in golf courses and parks.

Fixed-head sprinklers are designed to operate at pressures of 15 to 40 pounds per square inch. They cover areas 15 to 25 feet in diameter with a fine spray fairly evenly distributed. Some overlap is required. Rates of discharge vary from 1.5 to 5 gallons per minute. This is

equivalent to an application rate of 0.7 to 3.0 inches per hour, a rate too high for most soils to absorb so that runoff or puddling results.

Fixed heads are sometimes used on portable under-tree orchard systems on permeable soils. Their cost per unit is low. For other orchard and field uses on less permeable soils, their application is limited.

Nozzle lines. Nozzle lines are usually stationary. They are relatively expensive, and so they are generally used only for crops yielding a high gross return, such as certain truck crops and small fruits, and for nurseries, greenhouses, lawns, and other special purposes.

The nozzle lines are, as a rule, parallel lines of pipe, $\frac{3}{4}$ to $1\frac{1}{2}$ inches in diameter, each fitted with a row of small brass nozzles spaced 2 to 4 feet apart. The common height is 4 feet above ground, but they may be as high as 7 feet where passage underneath is needed for cultivation. Sometimes the pipe is held up by a suspension cable slung from much higher poles set 100 to 200 feet apart.



Stationary nozzle line for irrigating strawberries. An oscillating motor at the head of the line slowly rotates the pipe back and forth so as to wet a strip on each side. The nearest jets are different from the others; they come from special nozzles being tested.



Portable perforated line irrigating young alfalfa. This system operates at low pressure.

To wet a strip on both sides, the pipes are slowly rotated through an angle of about 90 degrees (from about 45 degrees on one side to the same on the other). This can be done either by hand or by a water-operated oscillating motor. The oscillators are usually double-acting piston devices. Being fairly expensive, they are made to do multiple duty. Sometimes they are moved from line to line; in other cases they operate several parallel lines at one time by means of cables attached to arms on each line. A special union is required to permit the oscillating movement needed to give uniform coverage of the area between sprinkler lines.

Nozzle lines generally operate at pressures of 25 to 40 pounds per square inch. At 30 pounds the nozzles in common use can deliver 0.15 to 0.30 gallon per minute. Where the pressure is adequate, the lines are spaced about 50 feet apart.

The nozzles, being small, clog easily. Water containing algae or other clogging matter must be screened, and this is done usually at the head of the line.

Perforated pipe. Lightweight portable pipe with holes so spaced in its sides as to discharge water at various angles is

available. The spacing of the small holes varies, depending on the rate of water to be discharged. This pipe is available in types applying from $\frac{1}{2}$ to 2 inches per hour or more. Perforated pipe should be used only on soils that will absorb water at relatively high rates.

This type of system has the advantage of performing at relatively low operating pressure—from a maximum of about 20 to as low as 4 or 5 pounds per square inch.

Distribution of water from a line is fairly uniform. The width of the strip wetted depends on the pressure, varying from approximately 50 feet at 20 pounds per square inch to 20 feet at lower pressures.

Besides applying water at relatively high rates, perforated pipe has other limitations. Since the pipe is laid on the ground, plants may grow so close and high that they impinge on the water jets. It is impossible to regulate or equalize the pressure along the line, as with sprinkler heads, except possibly by changes in pipe diameter. Therefore, the system operates most efficiently when it is used on level land or on a contour line.

Perforated plastic pipe or tubing.

Perforated plastic pipe is still in the experimental stage, particularly for agricultural purposes. However, for irrigating irregularly shaped turf areas or floricultural beds, flexible pipe or tubing offers considerable promise.

Two basic types are available—a soaker hose and a sprinkler hose. The soaker hose is a single tube that has many small perforations on the bottom or around the entire circumference of the tube. Discharge from the perforations varies with pressure, and considerable variation may occur along a length of hose. The application rate, when computed for a narrow wetted strip of 1 foot, is relatively high—in excess of 1 inch per hour. However, since most soils will not absorb water at this high rate, the water floods across the soil surface, wetting a strip 2 feet wide or more, depending on the infiltration capacity of the soil.

The sprinkler-hose type usually consists of one to three parallel tubes with perforations only on the top. The extra width gives the unit stability and keeps it from rolling over. The perforations may be punched or burned, and they vary in size and spacing. The burned holes give somewhat better control.

Water application rates vary for each type of hose and perforation, but in general they tend to be high. Spacing for the sprinkler hose should be from 10 to 15 feet. Observation of the uniformity of spray height from the hose will help in making proper adjustments in length and spacing of the hose.

Stationary, semiportable, and portable systems

Stationary systems. Stationary types were once the most popular sprinkler systems in California farming. Most of the original orchard systems were of this type, with rotating sprinklers mounted on high risers over the trees.

Today, however, except for special situations, few stationary systems are being installed.

A few growers of potatoes and specialty crops, who have light sandy soils and irrigate every two or three days, are using a form of a permanent-type system. After planting, portable surface pipelines are placed at proper intervals and left in that position until time for harvest. Increased yields and reduced labor costs help offset the high investment cost, which may be four to six times that of a portable system moved regularly.

A stationary system, once it has been properly installed, with fixed or rotary heads to fit conditions, has certain advantages over a portable system. For example, it can duplicate a known performance over and over. In addition, it takes less attention and costs less to operate than a portable system, which must be shifted about from place to place.

On the other hand, its pipelines, which supply water to the risers, interfere with cultivation unless they are buried fairly deep; the risers and their attached sprinklers may also interfere unless extra precautions have been taken in planning. More important still, the initial investment is quite high, often approaching \$1,000 per acre.

Stationary system with fixed high risers used in sprinkling an orchard.



Semiportable systems. Some sprinkler systems have stationary pipelines and portable sprinklers. They are especially adaptable for orchards and for the turfs of golf courses and parks. They are less expensive than stationary systems and do not present some of the difficulties of portable systems.

Frequently, in semiportable systems, the portable sprinklers are of the under-tree type. A satisfactory arrangement used in some foothill areas of the Sacramento Valley is a pipeline down every other tree row, with a valve between every second and third tree. To this valve is attached a hose and sprinkler which can be set at four positions between trees. Sometimes high risers are used for overhead irrigation. In another type of semiportable system a permanent pipeline is placed down every eighth or tenth tree row with an outlet valve between every third and fourth tree. A flexible hose with four or five sprinklers is attached to the valve, permitting irrigation on both sides of the pipeline.

Portable systems. A portable system usually consists of a main distribution line, which may be portable or permanent, and one or more lateral lines of portable, lightweight pipe to which sprinklers are attached. In a completely portable system all of the pipe and pump would be portable.

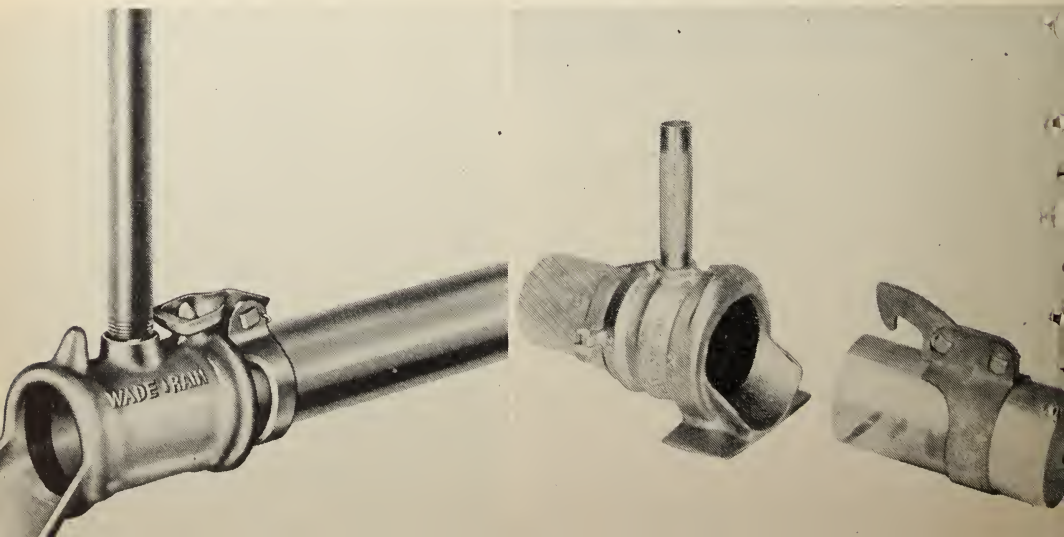
If steel pipe is used as a buried main line, 12-gage metal is recommended, and the pipe should be at least single-dipped in hot asphalt to give reasonable service under average conditions. Steel pipe is connected by couplers, by welding, or by driving tapered ends together. When a driven connection is used, the asphalt coating should be uniformly heated so that it is soft but does not run off the pipe before the joint is driven together. Transite pipe has carefully tapered ends that accommodate a coupling with rubber "O" rings, which slides over the pipe and secures the joint.

When the pipe is buried, it should be placed deep enough to protect it from heavy loads and cultivating equipment. Normally, soil cover of 18 to 24 inches is desirable.

Risers with valves need to be placed at intervals along the main pipeline to which the lateral lines are connected. The most convenient spacing is to use the same interval between valves as between laterals. However, since risers and valves are expensive, it is common practice to use one riser for every three lateral settings. A length of portable pipe equal to the spacing of the lateral lines is used as a "jumper" connection.

Portable sprinkler pipe comes in standard lengths of 20, 30, and 40 feet; other lengths can be furnished on order.

A few of the many types of portable sprinkler pipe couplings . . .



Special aluminum alloys are used in the manufacture of lightweight sprinkler pipe to provide strength and resistance to corrosion. Pipe is manufactured by extrusion, drawing, or welding.

Sections of portable pipe are connected to each other by a quick-operating coupling. The type of coupling used is the major difference between the various portable irrigation systems. Most couplings permit the operator to couple or uncouple the connections from any location along the pipe. Some type of foot-ing device is desirable to keep the pipe and coupler from tilting or rolling.

In general, a coupling contains at least one rubber gasket. The water pressure holds the gasket tightly in place against the pipe, thereby preventing leakage as the flow continues from one pipe to the next. This arrangement provides for a rather loose coupling and for flexibility of the line so that it can follow relatively rough land surfaces.

To prevent leakage and provide flexibility, the gaskets are carefully manufactured. Most of those available today are similar in design and constructed of special rubber or plastic. Although plastic gaskets have a more uniform surface than rubber, they have the disadvantage of changing in flexibility with variations in temperature. Cold water or low temperatures may make them brittle.

Gaskets can be expected to deteriorate and will need to be replaced. Their length of service will depend on local operating conditions. Factors contributing to deterioration include heat and dirt. When the sprinkler system is not in use and is exposed to the intense summer heat, deterioration can take place rather rapidly, as the pipe and couplings will absorb a large amount of heat. Each time the pipe is uncoupled, some soil may be picked up on the end of the pipe or in the coupling and cause abrasion to the gasket when the pipe is recoupled. Suspended material in the water supply will also tend to cause wear on the gasket.

The following suggestions will aid in giving longer life to your gaskets:

1. Eliminate suspended material from the water (this will reduce maintenance and repair of the pump and sprinkler heads, too).

2. Dust new, sticky gaskets with a fine powder, such as soapstone or talcum. Do not use oil.

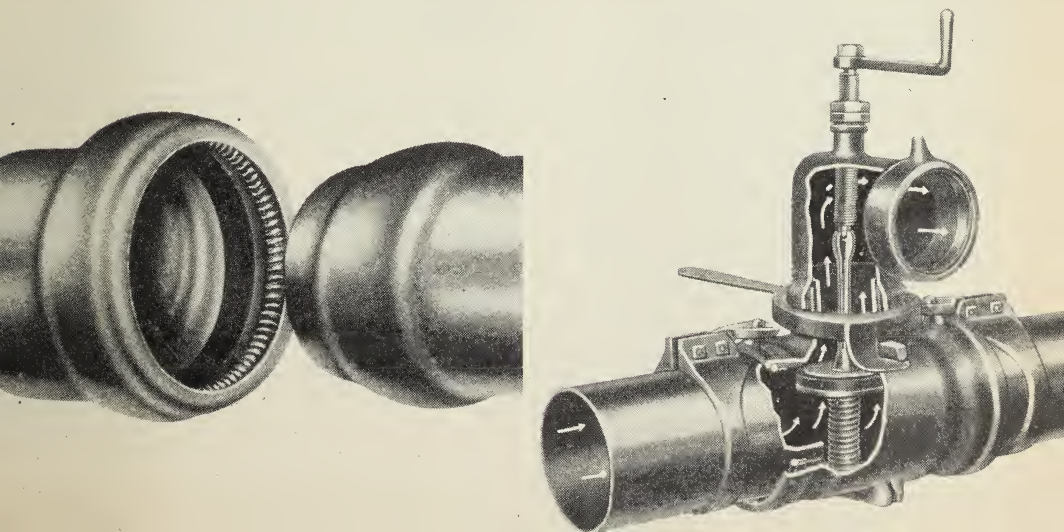
3. Wipe excessive dirt from each gasket before reassembling.

4. Do not leave the sprinkler system in direct sunlight.

5. Provide cool, dry storage, if possible, for the system when it is not in use.

6. Remove the gaskets at the end of each season and store them in a barrel of water.

... and on the right, one type of valve-opener elbow.



Other fittings for portable systems may include ells, tees, reducers, plugs, tee-type valves for mainline hydrants, and valve-opener elbows.

In most systems the couplings contain the outlets to which the sprinkler-head risers are attached; in others, the outlets are attached directly to the pipe.

The distance portable lateral lines are moved for each setting is usually 40, 50, or 60 feet, depending on the application rate, the time required to cover a field, and wind conditions. After each set the pipe is uncoupled and carried to the next position. The number of men required to move the pipe efficiently depends on the length and weight of the pipe, the height and density of the crop, and the type of soil. The experience and ability of the men will also be a factor.

Many farmers have constructed low trailers to transport the pipe from field to field. These are constructed with either two or four wheels.

Axial-move system. In this system the portable lateral line is moved as a unit from one position to another in the direction of the pipeline or axis. This system cuts labor costs, as no uncoupling, carrying, or recoupling of pipe sections by hand is required.

Two moving methods are possible. In one, skids are attached at each joint, supporting the line off the ground. A move is made by attaching a clamp to the end of the line and towing it with a tractor or jeep. This method operates best on a permanent turf or well-established, low-growing cover crop. It should not be used on rough land because abrasion of aluminum pipe will cause rapid wear.

The other method is to mount the sprinkler pipe on dollies every 30 to 40 feet. Each dolly has two wheels parallel to the pipe. A move is made in the same manner as in the previous method.

A number of mechanical improvements are being made in mounting wheels to provide greater flexibility in moving lateral lines. One device includes a uni-

versal joint and mounting for two rubber-mounted, ball-bearing wheels. This permits a great degree of flexibility in turning corners and is designed to keep the riser vertical at all times. The light weight of each flexible unit, coupled with ball-bearing wheels, results in a minimum of resistance when the pipe is moved.

An even more flexible device has a pair of wheels attached to a dolly in such a way that they can turn through an angle of 45 degrees from a position parallel to the pipe. The pipeline can thus be towed sideways to the next lateral position.

Lateral-move systems. In another adaptation of a portable system, a wheel is mounted perpendicularly to the pipe at each 30- or 40-foot joint. This combination makes a complete mobile unit that can be moved laterally from one setting to another by a ratchet or by power drive. One man can move as much as a quarter of a mile of lateral pipe at one time.

The initial cost of wheel-type systems is relatively high, but savings in labor and convenience may justify the investment. It should be pointed out that it is more difficult to move a wheel-type system from one field to another than a hand-moved system.

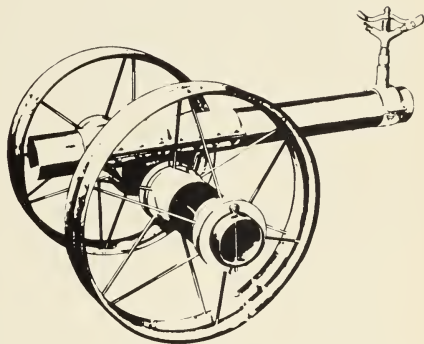
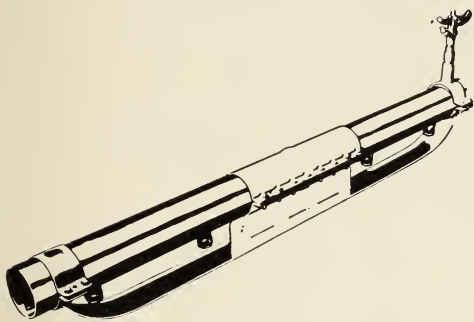
Traveling sprinkler machines. A few growers use traveling sprinkler machines that pump water from a ditch and distribute it through large sprinkler nozzles mounted on the machine. These machines move continuously along the ditch; most of them are geared to move 1 to 5 feet per minute.

Operating pressures vary from 60 to 150 pounds per square inch. One or more sprinklers, each discharging from 200 to 800 gallons per minute, are used. In some cases this rate of discharge would be far beyond the soil's capacity to absorb water. The diameter of coverage may be as great as 300 feet.

For this type of operation an adequate water supply must be available; also supply ditches at required intervals must be constructed and maintained. This limits



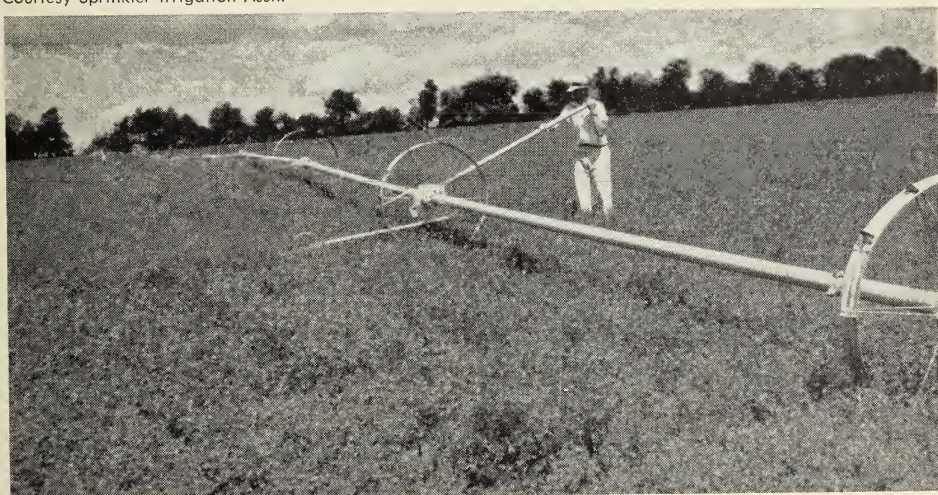
A four-wheeled trailer used for transporting pipe around the field or from one field to another. Pipe may be stored on trailer when not in use.



Above—sled- or skid-type attachment, and right—wheel-dolly attachment. These are used for longitudinal movement of pipes.

A wheel-mounted, portable sprinkler on a pasture. This type of rig is used for lateral movement of pipe.

Courtesy Sprinkler Irrigation Assn.



the operation to lands where ditches are feasible. Furthermore, each ditch, including the tractways along each side, removes some land from production. This may amount to 5 or 10 per cent of the field.

While the labor of moving pipe is removed, pumping costs are greater because of the higher pressures, and maintenance of the machine and water-supply ditches must also be considered.

Self-propelled systems. Recently, automatically controlled self-propelled units have been developed. Large wheel towers support the pipe 6 to 7 feet above the ground. The system moves in a circle around a pivot point where water is delivered into the system. Each tower is driven by a stroke of a hydraulic cylinder which operates on the normal water pressure. The size of sprinklers is increased

toward the end of the line to compensate for the larger area covered. The system can be engineered to turn on or off automatically.

Maintenance and storage

Regardless of the type of system, annual inspection is good practice. Pipe, sprinklers, couplings, gaskets, and any other appurtenances should be carefully examined and any repairs made before each season's operations. Particular attention should be paid to the sprinklers, making sure all bearings and bushings are in proper adjustment and that excessive sand conditions have not enlarged the nozzle openings.

Adequate storage for the equipment is recommended. The pipe should be carefully stacked and stored under a shed at the end of the season.

DESIGN and OPERATION OF SYSTEMS

The design of a well-planned sprinkler system calls for a knowledge of engineering and agricultural principles; it cannot be executed by simple rules of thumb. Each area or field presents individual problems that must be analyzed and considered in the design of the system if it is to operate efficiently.

What conditions must be considered?

The conditions that will influence the design of a sprinkler system are, in brief: the requirements and limitations of the crop, the nature of the soil, the water supply, the size and shape of the field, arrangement and layout of the system,

and the cost. Other cultural practices and farm-management problems should also be kept in mind.

The subcommittee on sprinkler irrigation of the American Society of Agricultural Engineers has recommended certain minimum requirements of design, which serve as helpful guides. These are, briefly:

1. The system should meet peak moisture requirements of any regularly irrigated crop and apply a stated amount of water in a specified time.

2. The application rate should not cause runoff.

3. The pressure and spacing should be designed to apply water uniformly.

THE CROP—ITS REQUIREMENTS AND LIMITATIONS

Efficient sprinkler irrigation meets peak crop needs and takes care of field application losses. Here are the key points of plant growth in relation to water needs.

Crop production is the prime consideration. Water must be supplied in the amounts necessary to maintain steady and continued crop growth.

Rooting characteristics

Among the most important crop factors are the rooting characteristics, which include rooting depth and distribution. These are frequently overlooked, or in many cases not fully understood.

A guide to the effective rooting depth of certain vegetable, field, and orchard crops is given in table 1. It should be noted that these measurements are for mature crops grown on deep, well-drained soils under average conditions. There are exceptions and variations.

Irrigation methods vary depending on whether the crop is deep- or shallow-rooted. For example, where all of the soil to the full effective rooting depth is

Table 1. Depths to Which the Roots of Mature Crops Will Exhaust the Available Water Supply When Grown in a Deep, Well-Drained Soil under Average Conditions

Crop	Depth	Crop	Depth
	feet		feet
Alfalfa	8 to 12	Hops	6 to 8
Almonds	6 to 9	Permanent pasture	1½ to 3
Apricots	6 to 9	Lettuce*	1
Artichokes	4½	Melons	5
Asparagus	10	Milo	6
Beans (bush)*	1½	Mustard	3½
Beans (lima)	4	Olives	6 to 9
Beets (sugar)	5 to 6	Onions	1
Beets (table)	3	Parsnips	4
Broccoli	2	Peas	3½
Cabbage	2	Peaches	6 to 9
Cantaloupes	4 to 6	Pears	6 to 9
Carrots	3	Prunes	6 to 9
Cauliflower	2	Peppers	3
Celery*	2	Potatoes (Irish)*	1½
Chard	3	Potatoes (sweet)	4 to 6
Cherries	6 to 9	Pumpkins	6
Citrus	4 to 6	Radishes	1½
Corn (sweet)*	3 to 4	Spinach	2
Corn (field)*	5 to 7	Squash (summer)	3
Cotton	4	Sudan grass	6 +
Cucumber	3½	Tomatoes	6 to 10
Eggplant	3	Turnips	3
Figs	5	Strawberries	2 to 3
Grain and flax	5	Walnuts	12 to 18
Grapes	6 to 8	Watermelons	6 to 8

* Crops known to have sparse or skeleton-type root development during early stages of growth.

utilized for storing soil moisture, and the crop is deep-rooted, fewer irrigations are needed, and irrigation efficiency is increased.

The rooting characteristics of annual and perennial plants differ considerably. Perennial crops, such as fruit trees, generally have well-developed root systems that permeate the entire soil depth, generally 4 to 9 feet. Rooting characteristics of annual crops, on the other hand, are quite variable. They have continually enlarging root systems, particularly during the earlier stages of growth. What is at first a skeleton system may develop later into a very complete system. Some have deep roots, others very shallow ones. Some have very sparse or less vigorous root systems than others. Even though a plant may send its roots very deep, they may permeate only a small part of the soil mass. As a result, the plant may wilt or cease to grow even though the soil moisture is generally at a high level throughout that part of the soil mass which is not in contact with the roots.

Other conditions that may modify root development include the presence of hardpans or any dense, compact layer or layers, a high water table or salt accumulation in the soil, or diseases and root insects.

Another point to consider is that in irrigating some deep-rooted crops, it is not desirable to wait until all of the readily available soil moisture has been depleted in the entire rooting depth. The

time required to apply water to an entire field should be estimated, and irrigation should be completed before soil moisture is completely lost from any part of the field.

The amount of readily available moisture held by the soil in the effective rooting depth depends on the soil characteristics. This subject is discussed on pages 21-23.

Water use

Transpiration. The rate of water use by a crop (transpiration) depends on certain plant characteristics and climatological factors. Long hours of sunlight, high temperature, low humidity, and strong winds all tend to increase the rate of water use providing moisture is readily available in the major part of the root zone.

Changes in the rate of transpiration occur during a growing season. The rate is less for young plants with few leaves or mature plants in poor growth than for those with abundant leaf surfaces and dense stand and in good vigor. It is low early in the season and tapers off in the late summer and fall. In California the peak use of water may occur any time during June, July, or August, or, in some years, even September. Peak use may last only a day, or it may continue for two weeks or more. The capacity of the sprinkler system should be great enough to satisfy the needs of the crop during this peak period.

Table 2. Estimated Peak Water Use of Crops in Five Geographical Areas of California

Area	Water use (Inches per day)
Dry desert.	0.30 to 0.40
San Joaquin Valley.	0.25 to 0.35
Sacramento Valley.	0.20 to 0.30
Inland Coastal areas.	0.15 to 0.20
Coastal slopes.	0.10

Evaporation. Closely associated with the use of water by transpiration is the water evaporated from the soil surface. The same climatic factors that control transpiration also control the rate of evaporation. However, evaporation losses during the growing season are usually much less than the amount used in transpiration because evaporation takes place only when the soil surface is wet and to a limited depth—4 to 8 inches, depending on the soil type and the frequency of irrigation. A loss of 0.2 to 0.5 inch following each irrigation can be expected.

The combined use of water in any given time and area by crop transpiration and evaporation from the soil surface is called the **water use** of the crop.

Values of the estimated peak water-use rate for five geographical subdivisions of California are given in table 2. These rates are for mature crops in good growing vigor, completely shading the soil. The absolute rate for a specific crop at any time will depend on the plant characteristics and climatic factors discussed above.

Other water losses. It should be noted that the rates given do not include other losses or factors that determine the field-application efficiency of the system. These include: evaporation from the spray and wetted foliage, deep percola-

tion, runoff, unavoidable losses, unevenness in the distribution pattern, and breakdowns or repairs. These must be considered in determining the peak gross water requirements of the sprinkler system.

The evaporation loss from the spray and wetted foliage may be appreciable, particularly under conditions of low application rates, high temperatures, and low humidity. Strong winds also contribute to a high loss, for some water may be carried out of the area being sprinkled.

Evaluation of the loss from the spray is difficult, but experiments indicate it can be as much as 5 per cent of the water discharged by the nozzles.

The loss from the soil and foliage during an irrigation may be relatively high because sprinkling wets practically all of the plant foliage and generally more soil surface than surface irrigation does. The extent of these losses depends on the factors already mentioned, but it may amount to 5 to 35 per cent of the water applied.

The field-application efficiency of well-designed sprinkler systems may vary, on the average, from 50 to 90 per cent.

A properly designed sprinkler system must, therefore, apply a sufficient depth of water not only to meet the peak water requirements of the crop but also to take care of the field-application losses.

THE SOIL AND ITS CHARACTERISTICS

How soil type and structure influence water-application rates.

Infiltration capacity

The rate at which water enters the soil is known as the soil's infiltration capacity. This rate varies greatly depending on the type and structure of the soil. Sandy soils usually take water faster than loams and clays. Soils that have been compacted or are lacking in good tilth take water slowly.

The infiltration capacity also varies

during the time of water application depending on soil-moisture conditions. If the soil is dry, the water intake will be relatively high at the beginning of an irrigation. However, the infiltration rate may decrease rapidly during the first few hours of an irrigation and then gradually become constant.

A sprinkler system should, therefore, be designed to apply water at such a rate

that the soil will absorb it throughout the entire sprinkling period without producing surface runoff. The rate of application should be designed for the slowest intake rate, and water should be applied uniformly to all parts of the field.

For many clay soils, which have a low infiltration capacity, the application rate should not exceed 0.3 inch per hour. Application rates up to 0.5 inch per hour can be used on most loam soils, whereas sandy soils may take water in excess of 1 inch per hour.

There are many exceptions to these general rates. The proper application rate for a particular soil type can be determined only by experience. In some cases it may be necessary to make several trial irrigations, varying the operation of the system by changing sprinkler nozzle sizes, line pressure, or lateral spacing, and observing field conditions. Adjustments can then be made to meet as closely as possible the infiltration capacity of the soil. It should be remembered that a change in operation or design to meet one factor must be integrated with the other features of the system to maintain efficient operation.

In some cases the rate of application may exceed the infiltration capacity because of soil differences within a given field, and water may collect on the surface. It may be necessary to provide some surface drainage so that crops growing in low spots in the field will not receive excessive amounts of water.

Water-holding capacity

During an irrigation, water enters the soil and fills the pore space between the soil particles. When all of the space is full, the soil is saturated. In general, this is a temporary condition, for once irrigation is completed some of the water moves downward. In most soils this downward movement practically ceases after one to three days. The moisture retained in the wettest portion of the soil is called **field capacity**.

The amount of water held at the field capacity depends on the soil texture, structure, uniformity, and depth. It may range from less than 1 inch per foot of depth for a sandy soil to 3 inches or more for some clays. A shallow soil with poor drainage will hold more water per foot of soil when at field capacity than will a deep soil with poor drainage.

Another important soil-moisture condition is the **permanent wilting percentage**. This soil condition is reached when the soil particles hold the water so tightly that plant roots are unable to absorb it rapidly enough to supply the needs of the growing plant. Some plants show this condition by a wilting of the leaves. Others may show it by a change in leaf color or by slower growth of the plant or fruit. Still others may not show any visible signs, yet their normal growth functions are essentially stopped until more water is added to the soil.

The soil-moisture content between the field capacity and the permanent wilting

Table 3. Average Readily Available Moisture for Various Soil Types*

Soil type	Readily available moisture (Inches per foot)
Sands	0.5 -0.75
Loams	0.75-1.50
Clays	1.50-3.00

* These quantities are given only as an approximate guide, since some sands may hold more readily available water than clays.

percentage is known as the **readily available moisture**. As long as the *major* part of the root system of any plant is in contact with soil containing readily available moisture, the plant can continue to function normally. The average readily available moisture per foot for the three general soil types is given in table 3.

A soil tube or auger is invaluable for examining the soil profile to observe conditions under which the roots of the crops are growing. With it you can obtain soil samples from various depths to see if the soil moisture has been depleted. It is also handy for determining the depth of soil wetted after an irrigation.

WATER SUPPLY MUST BE ADEQUATE AND RELIABLE

Factors to consider are: quantity and reliability, water quality, the water level (if the source is a well), and the location of the source.

Quantity

The source of water may be a stream, lake, farm pond or reservoir, an open ditch or canal, or a well. Whatever the source, the reliability and adequacy of the supply is most important. You must be sure of enough water to maintain steady and continuous crop growth for the entire area to be irrigated.

A continuous flow of water is essential for the most efficient use of a sprinkler system. Full-time use of the system during the peak of the growing season means a lower initial investment and lower annual operating costs. The rate of flow needs to be enough to satisfy the peak water use of the crop and cover field application losses. Sprinkling can use smaller rates of flow more efficiently than other methods.

Quality

The quality of the water and the amount of suspended material it contains must also be considered. The water should be analyzed to make sure that it is suitable for irrigation use. Water high in total salts, for example, may be injurious to some plants. Also important are the amounts of chlorides and boron and the ratio of sodium to calcium.

Silt and debris may cause needless wear on the mechanical parts of the pump and sprinkler heads. Also, debris or moss may clog or plug the nozzles of the sprinklers, requiring additional labor.

Whenever water is pumped from a ditch or stream, a screen or strainer is usually provided at the intake. It may be necessary to install a screening and desilting chamber or sediment trap under some conditions.¹ Water from a well is usually free of debris, but in some cases it may contain sand.

Location of the water level

Water-level conditions are important if the source is a well. When a pump is turned on, the water is quickly drawn down from the static to the pumping water level. The amount of drawdown will depend on the water-bearing characteristics of the materials supplying water to the well and the amount of water being pumped. Assuming that the speed of the pump is constant, the pumping level in the well may drop with time. This may occur during a day, throughout a season, or from season to season. Reasons for this can be mutual interference of adjacent wells, intensified pumping during the summer, or a general lowering of water levels within a ground water basin. Should the level be lowered, the capacity of a given pump will be reduced. This may have serious consequences if a sprinkler system is designed to operate

¹ Details of a desilting device may be found in "Desilter in the economy size," by M. W. Hoisveen, in *Irrigation Engineering and Maintenance* 4(2) : 11-12, 26, February, 1954.

at a given capacity and a reduction takes place because of a drop in the water level.

Careful study of the water-level conditions is very important if you are thinking of installing a sprinkler system. A test of the well is invaluable. In making the test, be sure to take into consideration the time of year and make certain that results are interpreted accurately for the lowest possible water-level conditions at other seasons. Once a system is in operation, the water level should be checked frequently—this will help to determine if the proper amounts of water are being applied.

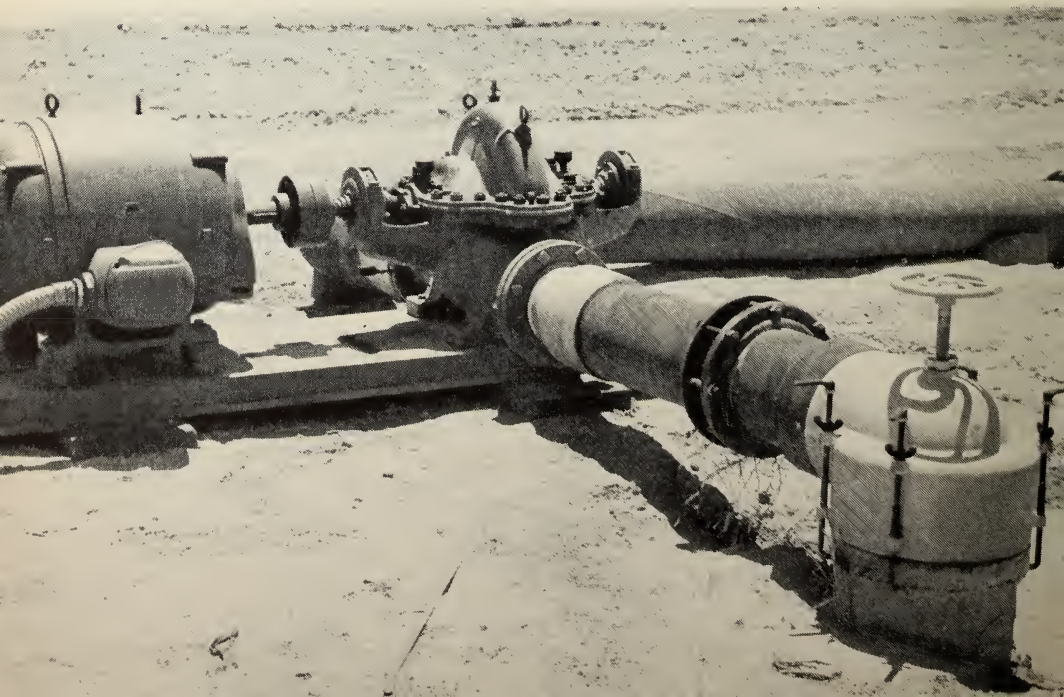
Proximity of the water source to the field

The relative location of the water source to the field or fields to be irrigated may dictate the type of sprinkler system to install and the method of operation. In many cases open ditches offer flexibility in operation. When topography permits, ditches can be constructed at convenient intervals and locations. In general, most sprinkler systems will be less expensive if the source of water is located at or near the center of the field.

Existing concrete pipelines can be used to carry the water from a well or canal to the field. Since ordinary concrete irrigation pipe is not designed to carry water under pressures greater than 8 to 10 pounds per square inch, a booster pump must be used to develop the pressure required after the water leaves the concrete pipeline. This pump can be a portable or permanent unit.

In some foothill areas of California, a water supply can be developed from springs or streams. Often these are high enough to develop the necessary pressure to overcome the pipe friction loss and operate the sprinkler system properly. The pressure lost because of friction will depend on the difference in elevations, length and size of pipeline, and rate of water flow. Most rotating-type sprinkler systems require a pressure of 40 to 60 pounds per square inch at the upper end of the main pipeline. This corresponds to an elevation of 90 to 140 feet, which would be the absolute minimum difference in elevation from the point where the water supply is tapped to the sprinkler system.

A 60-horsepower motor and centrifugal pump used as a booster unit. Water is pumped from a concrete pipeline into a 10-inch steel main line.



THE PUMPING PLANT IS THE HEART OF THE SPRINKLING SYSTEM

Pump and power unit should be carefully chosen to make sure they will meet all of the operating conditions. Here is information that will guide you in your selection.

The pump

To obtain the most efficient pump for the intended service, choose a well-constructed, compact pump with good hydraulic characteristics, which, at a given speed, will meet the maximum head-capacity requirements of a properly designed sprinkler system. Naturally, a high operating efficiency is desirable and is usually obtained when the pump is new. However, it should be expected that with use the efficiency will drop, and in some cases the pump motor will become overloaded. Always inspect the individual pump curves before buying. These curves, which the pump vendor can supply, show the relationship between the quantity of water pumped and the operating head, efficiency, and brake horsepower.

Long hours of continuous operation place a heavy duty on the pumping equipment. The lower the operating speed of the pump, the longer will be its life. High-speed pumps (those operating at speeds in excess of 2,000 rpm), although lower in initial cost, may not be the most economical over a period of years.

The centrifugal pump is the type most commonly used when water is taken from a ditch or pipeline. The pump should not be located more than 10 to 15 feet above the water level. The biggest disadvantage of this type of pump is that it has to be primed; however, inexpensive devices, such as check valves, can be used to reduce or eliminate this difficulty.

In California, small positive displacement pumps are often conveniently attached to the centrifugal pump. These pumps are hand-operated and quickly take care of the priming problem.

When a cased well is the source of

water, or when the suction lift exceeds 20 feet, a deep-well turbine pump is used. Its major elements consist of a head-and-drive assembly above ground, from which the column and bowls are suspended. Since the pump bowls are submerged in water, no priming is necessary. With the proper design, a suitable bowl unit and adequate drive power can be used to lift the water to the ground surface and develop the pressure needed to operate the sprinkler system.

If a turbine pump is already available and is delivering the required amount of water for a sprinkler system but does not provide the pressure, a centrifugal pump with suitable drive power can be connected to the discharge of the turbine, and it will supply the needed additional pressure.

Power units

The type of power unit will depend on the speed and horsepower requirements of the pump. Most common in California on stationary pumping plants are electric motors. Their advantages include relatively low initial cost, simplicity of operation, and practically no repair or maintenance.

If the source of water is a surface ditch along the side of or through the field and no main-line pipe is used, a portable plant with an internal combustion engine is generally used. In such cases the pump is moved along with the lateral sprinkler lines. Gasoline and diesel oil are the common fuels used in these engines. Popular in California is a power and pump unit mounted on a truck bed or a trailer unit.

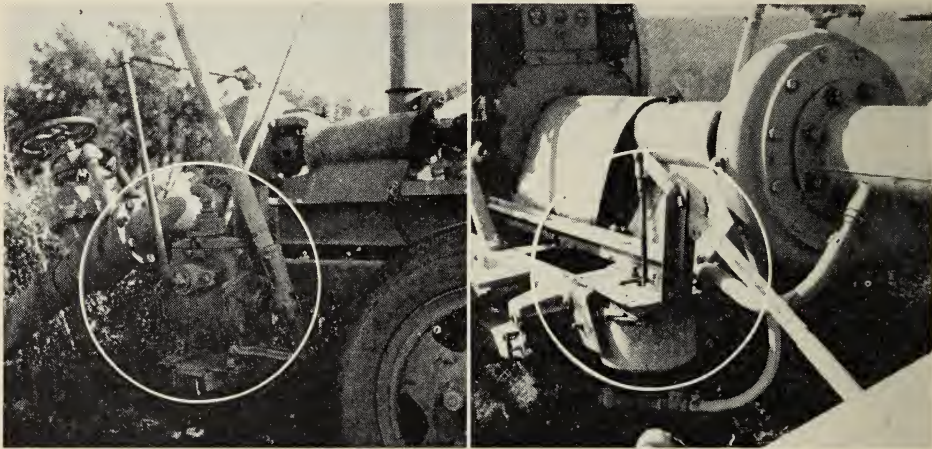
When natural gas is available, it can be used for portable booster pump units. Several quick-coupling natural-gas

valves, conveniently located in the field, will permit the portable unit to be moved around the field, pumping the water from a concrete line and discharging it under pressure into a portable main line.

The tractor type is another adaptation. It utilizes its own power both to operate the pump and to move from one location

to another. One disadvantage is that this ties up the tractor, which may be needed for other farm operations during the irrigation season.

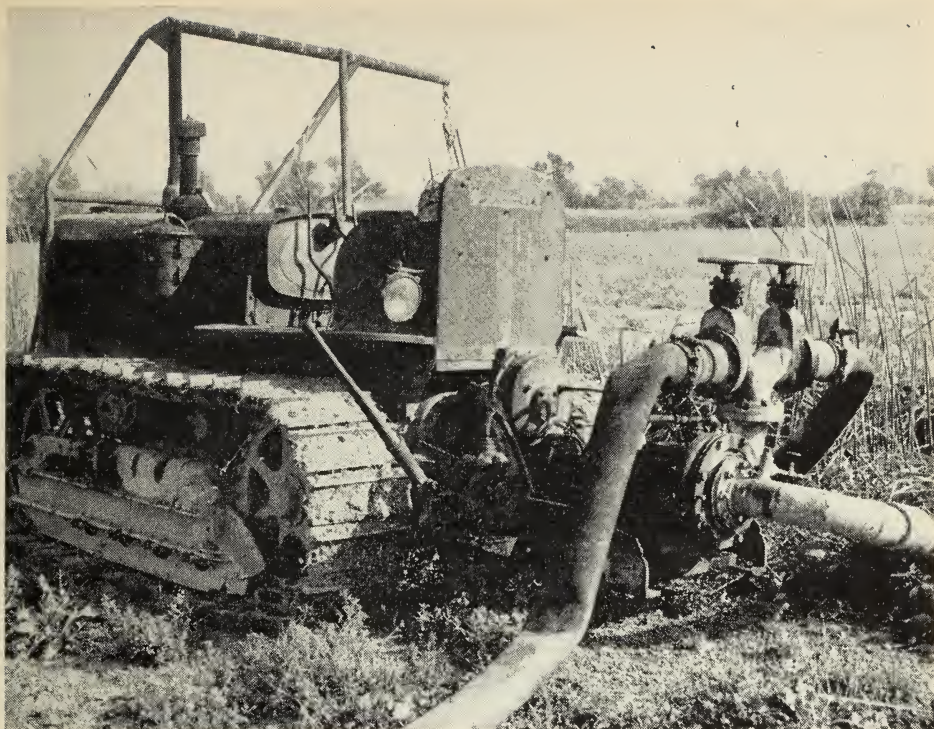
Small air-cooled engines are usually short-lived under the continuous operation required with many sprinkler systems.



Two types of small positive-displacement pumps used to prime the centrifugal pump.

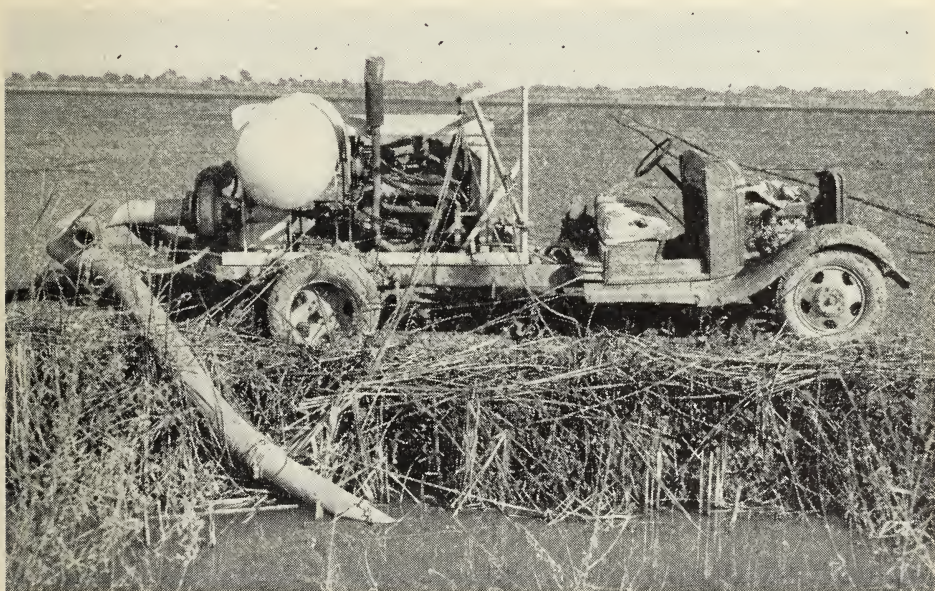
Motor and pump unit are sometimes mounted on trailers (below) . . .





... on a tractor, using tractor as power unit ...

... or sometimes on a truck chassis.



THE LAYOUT

Each field is an individual problem and all possible combinations of layouts should be investigated.

In general, most sprinkler systems will be cheaper if the source of water is located at or near the center of the field. In this case, shorter headers and lateral lines are generally feasible. This means smaller pipe can be used, lowering the initial cost of the system. Friction losses will also be lower than when a pump is at the boundaries of the field.

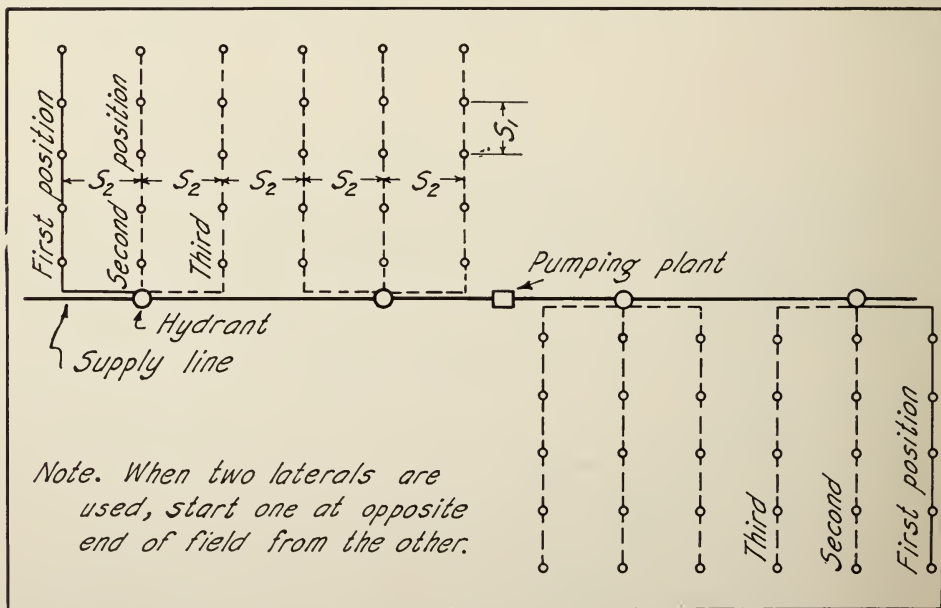
The water is supplied to the portable lines from risers and valves located along the pressure line. With two or more laterals, the pumping plants can be operated continuously. This arrangement, the most satisfactory from the standpoint of operation, may cost somewhat more than systems using portable plants. This is because a stationary main pressure supply line represents an investment usually greater than the cost of the portable pipe.

Friction loss in pipes

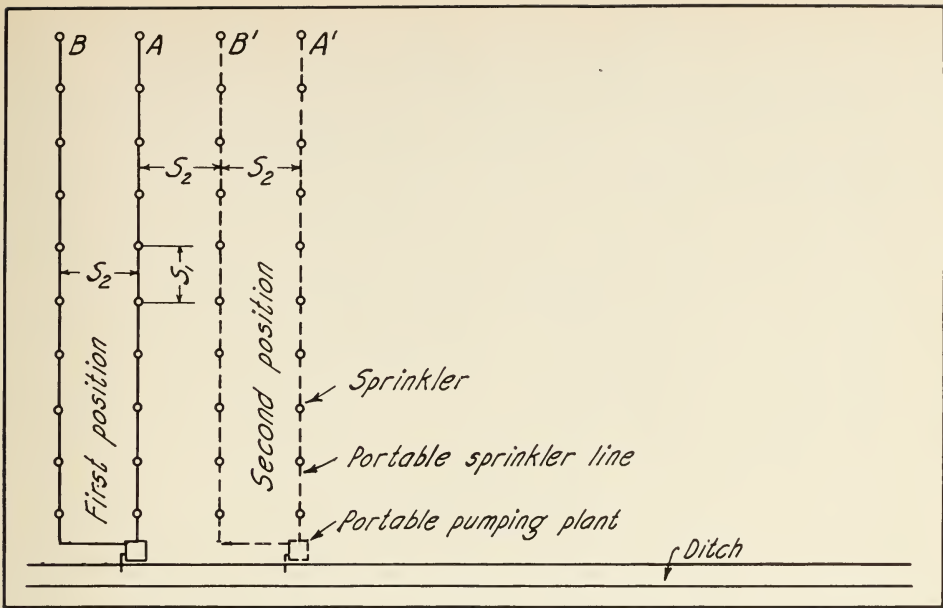
As water is conveyed along a sprinkler line, part of the energy or pressure developed at the upper end is lost by friction. The size and kind of pipe you select will depend on the amount of pressure loss due to friction for a given rate of flow, and on the general condition of the inside of the pipe. Calculation of friction loss in lateral lines is complicated in that part of the total water conveyed is discharged at each sprinkler.

In order to maintain reasonably uniform distribution and discharge from each sprinkler, consistent with economic considerations, certain general rules are suggested:

1. The friction loss in the main line should not exceed 15 per cent of the pressure available at the pump discharge.



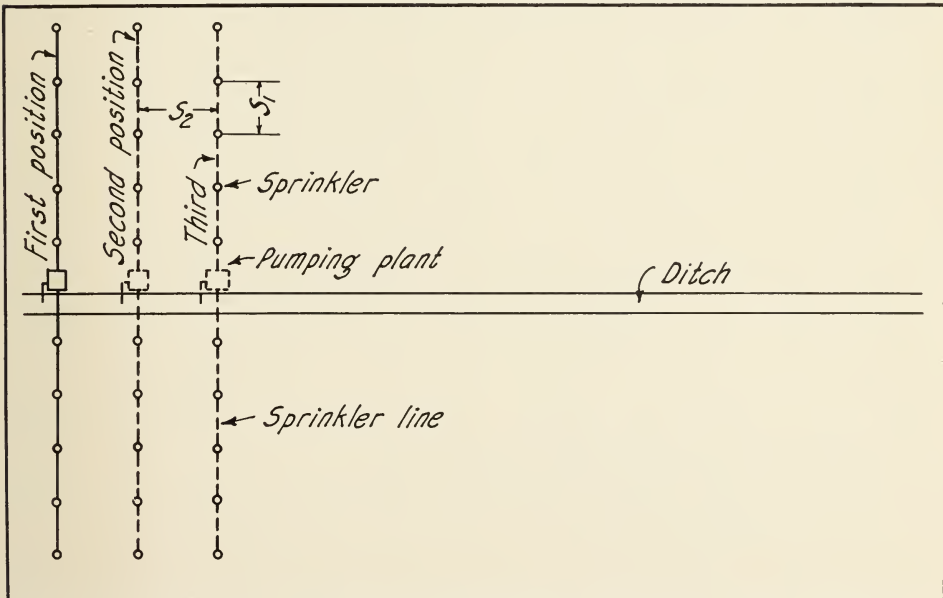
An arrangement of a portable system operating from a main pressure line with a stationary pumping plant supplied from a well. Jumper lines supplying the laterals permit three settings for each hydrant on the main. Often a single hydrant serves each lateral. Another procedure is to use the portable supply line on one side of the pump, then move it to the other side.



Single-line arrangement of a portable sprinkler system supplied from a ditch along one side of the field.

More specifically, pipe sizes may be selected by economic analysis comparing the fixed annual cost of pipe of different sizes with the annual operating cost of pumping against additional head when pipe of smaller diameter is used. Limits of head loss are established, based on local power or fuel cost and the number

Split-line arrangement of a portable sprinkler system supplied from a ditch running through the middle of the field. This is more economical than the single-line arrangement shown above.



**Table 4. Friction Loss in Aluminum Sprinkler System
Main Line with Couplers***

Flow (Gallons per minute)	Friction Loss Pounds per square inch (psi) per 100 feet of pipe								
	Pipe Size (inches)								
	2	3	4	5	6	7	8	10	12
10	0.14	0.02	....	....	....	....	....	....	....
20	0.52	0.07	....	....	....	....	....	....	....
30	1.06	0.15	....	....	....	....	....	....	....
40	1.80	0.25	....	....	....	....	....	....	....
50	2.90	0.39	....	....	....	....	....	....	....
60	3.72	0.52	0.13	....	....	....	....	....	....
70	4.77	0.69	0.17	....	....	....	....	....	....
80	0.91	0.22	....	....	....	....	....	....
90	1.08	0.27	0.09	....	....	....	....	....
100	1.39	0.35	0.12	....	....	....	....	....
120	2.08	0.52	0.17	....	....	....	....	....
140	2.60	0.64	0.22	....	....	....	....	....
160	3.38	0.85	0.29	0.12	....	....	....	....
180	4.07	1.00	0.36	0.15	....	....	....	....
200	5.11	1.30	0.44	0.18	....	....	....	....
220	1.52	0.52	0.21	....	....	....	....
240	1.77	0.61	0.25	....	....	....	....
260	2.12	0.71	0.29	....	....	....	....
280	2.51	0.84	0.35	....	....	....	....
300	2.86	0.97	0.40	0.18	....	....	....
350	3.68	1.21	0.52	0.25	0.12	....	....
400	4.42	1.60	0.65	0.31	0.16	....	....
450	1.93	0.79	0.37	0.19	0.07	....
500	2.25	0.95	0.43	0.24	0.08	....
550	2.64	1.08	0.52	0.27	0.09	....
600	3.29	1.38	0.64	0.34	0.11	....
650	3.89	1.58	0.73	0.39	0.12	0.05
700	4.55	1.79	0.82	0.45	0.15	0.06
750	1.99	0.93	0.49	0.17	0.07
800	2.29	1.04	0.55	0.18	0.08
850	2.51	1.17	0.61	0.20	0.09
900	2.81	1.32	0.68	0.23	0.10
950	3.14	1.45	0.76	0.25	0.11
1,000	3.44	1.60	0.82	0.28	0.12
1,200	4.98	2.34	1.17	0.41	0.17
1,400	3.16	1.64	0.54	0.23
1,600	4.02	2.12	0.69	0.29
1,800	4.76	2.60	0.87	0.36
2,000	3.16	1.02	0.43

* Based on Scobey's friction loss equation using $K_s = 0.40$.

2. The friction loss in each lateral line should not exceed 20 per cent of the pressure available at the head end of the lateral line. Changes in elevation should be taken into account when figuring friction loss.

Values for the friction loss in aluminum irrigation pipe with quick couplers are given in table 4. Table 5 gives values that can serve as a guide for selecting the proper size of lateral pipeline. In this table it is assumed that the friction loss

Table 5. Guide for Selecting Size of Pipe for Sprinkler Lateral Line*

Sprinkler discharge	Maximum number of sprinklers to use on single lateral line with:											
	20-foot spacing				30-foot spacing				40-foot spacing			
	Pipe size				Pipe size				Pipe size			
	2"	3"	4"	5"	2"	3"	4"	5"	2"	3"	4"	5"
g p m												
1.0.....	36	72	125	280	31	62	104	200	28	56	93	160
1.5.....	27	56	91	156	24	48	78	120	21	44	72	106
2.0.....	23	46	76	114	21	43	70	97	18	38	62	88
2.5.....	21	43	72	105	18	38	62	90	16	34	56	82
3.0.....	19	39	67	93	16	35	56	84	15	31	52	76
3.5.....	18	37	62	88	15	32	53	78	14	29	48	70
4.0.....	16	34	56	82	14	29	49	72	13	27	44	64
4.5.....	15	32	52	78	13	28	46	68	12	25	41	61
5.0.....	14	31	50	74	12	27	44	64	11	24	39	58
6.0.....	13	27	46	66	11	24	40	58	10	21	36	53
7.0.....	12	25	41	60	10	21	36	53	9	19	33	48
8.0.....	11	23	39	57	9	20	34	50	8	18	31	45
9.0.....	10	22	37	54	9	19	32	47	8	17	29	42
10.0.....	9	20	34	50	8	18	30	44	7	16	27	40
12.0.....	8	18	31	45	7	16	27	39	6	14	24	35
14.0.....	7	16	28	42	6	14	25	36	6	13	22	32
16.0.....	7	15	26	39	6	13	23	34	5	12	20	30
18.0.....	6	14	24	36	5	12	21	31	5	11	19	28
20.0.....	6	13	23	34	5	11	20	29	4	10	18	26
22.0.....	5	13	22	33	5	11	19	28	4	10	17	25
24.0.....	5	12	21	31	4	10	18	27	4	9	16	24
26.0.....	5	11	20	29	4	10	17	26	4	9	15	23
28.0.....	4	11	19	28	4	9	16	25	3	8	14	22
30.0.....	4	11	18	27	4	9	16	24	3	8	14	21
35.0.....	4	10	16	25	3	8	14	21	3	7	13	19
40.0.....	3	9	15	23	3	7	13	20	2	7	12	18
45.0.....	3	8	14	21	2	7	12	18	2	6	11	17
50.0.....	3	8	13	20	2	6	11	17	1	6	10	16

* Based on friction loss in entire lateral line being equal to about 20 per cent of the probable operating pressure.

Table 6. The Factors by Which the Friction Loss in a Pipe Without Sprinklers Must Be Multiplied to Obtain Loss in a Lateral Line with Sprinklers

Number of Sprinklers	Factor	Number of Sprinklers	Factor
1.....	1.0	16.....	0.365
2.....	0.625	17.....	0.363
3.....	0.518	18.....	0.361
4.....	0.469	19.....	0.360
5.....	0.440	20.....	0.359
6.....	0.421	22.....	0.357
7.....	0.408	24.....	0.355
8.....	0.398	26.....	0.353
9.....	0.391	28.....	0.351
10.....	0.385	30.....	0.350
11.....	0.380	35.....	0.347
12.....	0.376	40.....	0.345
13.....	0.373	50.....	0.343
14.....	0.370	100.....	0.338
15.....	0.367	More than 100.....	0.333

in the entire lateral line is equal to about 20 per cent of the pressure at the head end of the lateral. In table 6 are listed the values by which the friction loss in a pipe without sprinklers must be multiplied to obtain the loss in a lateral line with sprinklers.

Although the most economical design of lateral lines would call for a reduction in pipe diameter, since the flow is reduced by discharge from the sprinklers, many farmers prefer to use the same size pipe

for the entire lateral line. However, where several lateral lines are being operated from a main line, it may be desirable to reduce the size of the main-line pipe to conform to the amount of water being carried.

Details of the hydraulic design of the system, taking these factors into account, are generally left to a member of the sales company, qualified to provide competent engineering service.

THE METHOD OF OPERATION

Operation of the system is generally governed by the limitations of soil-infiltration capacity, soil moisture, depth of rooting, area to be covered, and water supply.

In situations where greater flexibility is possible, the operation of the system should be designed to fit farm-labor conditions. This is particularly important

when lateral moves must be made entirely by one man. Sprinkler-system operation should be coördinated as well as possible with routine work and other chores.

There are two general methods of operation. One is to apply water at a high rate and move frequently. The other is to apply water at a relatively low rate and move less often. The first, which is possible only on soils with high infiltration capacities, requires almost continuous labor. This means that on many farms the pipe would have to be moved throughout the night.

The second method is generally more satisfactory because the laterals can be moved at convenient times of the day. Most popular are sets of 7 hours (three moves per day) or 11 hours (two moves per day), allowing one hour for the move. The twice-a-day move generally applies enough moisture to wet dry soil to the necessary depth for most crops. Sets of 23 hours may be necessary for deep-rooted crops, such as alfalfa, or orchards growing on deep, permeable soils that have low infiltration rates. In these situ-

Terms of measurement used in this circular, particularly in the example problem, are referred to by the following standard abbreviations:

- ac.—acre
- ac.-in.—acre-inch
- ac.-ft.—acre-foot
- cfs—cubic feet per second
- gpm—gallons per minute
- hp—horsepower
- ppm—parts per million
- psi—pounds per square inch
- rpm—revolutions per minute

ations more equipment may be necessary to allow for the longer sets and still cover the area frequently enough.

Examine carefully all possible layouts for each method of operation to make sure that the maximum efficiency is achieved in both the sprinkler system and other farm operations.

Any one of the five approximate formulas given below can be conveniently used to compute the depth of water applied to a field:

$\frac{\text{cubic feet per second} \times \text{hours}}{\text{acres}}$	} = \text{acre-inches per acre, or average depth in inches}
$\frac{\text{gallons per minute} \times \text{hours}}{450 \times \text{acres}}$	
$\frac{\text{so. Calif. miner's inches} \times \text{hours}}{50 \times \text{acres}}$	
$\frac{\text{Calif. statute miner's inches} \times \text{hours}}{40 \times \text{acres}}$	
$\frac{96.3 \times \text{gpm per sprinkler}}{\text{sprinkler spacing} \times \text{lateral spacing}}$	

EXAMPLE PROBLEM

The following step solution can be used as a guide in fitting a sprinkler system to a particular field problem.

Basic Information

Crop:	Permanent pasture
Depth of rooting.....	2 feet (table 1)
Location:	Sacramento Valley
Peak crop water requirements.....	0.3 inch per day (table 2)
Soil:	Clay loam
Readily available water capacity.....	1.5 inches per foot (table 3)
Maximum infiltration capacity (estimated) ..	0.5 inch per hour
Area:	36.3 acres
Shape	1200 feet wide × 1320 feet long
Slope	Level
Water Source	Well in the center of the field with a discharge capacity of 400 gpm and a pumping water level of 55 feet below the center of the pump discharge pipe.
Irrigation efficiency (estimated)	75 per cent

The operator wants to move the system twice each day, allowing at least one hour for each move. He is willing to operate 7 days a week. This routine will fit into a well-planned pasture-management program.

Calculations

Amount of water available between irrigations ..	1.5 inches per foot × 2 feet = 3 inches
Number of days that can elapse before additional water must be added.....	$\frac{3 \text{ inches}}{0.3 \text{ inch per day}} = 10 \text{ days}$
Depth of water required per irrigation.....	$\frac{3 \text{ inches}}{0.75 \text{ (irrig. efficiency)}} = 4 \text{ inches}$
Total operating time per day.....	2 × 11 hours = 22 hours
Total rate of flow required.....	$\frac{36.3 \times 4}{22 \times 10} = 0.66 \text{ cfs}$
	0.66 × 450 = 297 gpm

The next step is to determine the lateral and sprinkler spacing. Two general conditions must be met: (1) for a given lateral spacing there must be enough laterals to cover the area during the irrigation interval; (2) the lateral and sprinkler spacing must permit a rate of water application not to exceed the maximum allowable for the soil—in this case 0.5 inch per hour. In this problem it will be best to lay a portable

main the short way of the field from the pump. It will be $\frac{1200}{2} = 600$ feet long. The laterals will be $\frac{1320}{2} = 660$ feet long.

Lateral spacing

Try 40 feet:

- One 660-foot lateral would move 80 feet per day. To cover the entire field would require $\frac{2 \times 1200}{80} = 30$ days. Since the irrigation interval is 10 days, 3 laterals would be required.

Try 50 feet:

- One 660-foot lateral would move 100 feet per day. To cover the entire field would require $\frac{2 \times 1200}{100} = 24$ days. Since the irrigation interval is 10 days, 3 laterals would be required; the field could thus be covered in 8 days.

Try 60 feet:

- One 660-foot lateral would move 120 feet per day. To cover the entire field would require $\frac{2 \times 1200}{120} = 20$ days. This spacing with two laterals would meet the irrigation interval requirement. It would be most satisfactory from the standpoint of less investment in pipe and lower labor cost of moving. If wind conditions prevail, shorter spacing is recommended.

Sprinkler spacing

If one man is to move the pipe, 30-foot lengths are desirable. With that length and a sprinkler for each pipe section, the number of sprinklers per lateral will be $\frac{660}{30} = 22$.

With two laterals the total is 44.

When 44 sprinklers are operating, each will be discharging an average of $\frac{297 \text{ gpm}}{44 \text{ sprinklers}} = 6.75 \text{ gpm per sprinkler}$.

Performance tables of sprinkler manufacturers will give the size and type of a sprinkler with given size nozzles that will discharge this rate at a given operating pressure. The pressure at the last sprinkler on the lateral should be approximately 35 psi.

Application rate

The application rate for sprinkler and lateral spacing of 30 and 60 feet will be $\frac{96.3 \times 6.75}{30 \times 60} = 0.36 \text{ inch per hour}$.

If 4 inches is applied during each irrigation at the rate of 0.36 inch per hour, the time required per set will be $\frac{4 \text{ inches}}{0.36 \text{ inch per hour}} = 11.1 \text{ hours}$, which agrees with the original condition of moving twice a day.

Main pipeline size. The main line will be 600 feet long. It must be large enough to accommodate the flow of 297 gpm for whatever layout of laterals is used. In the design of the main line it would be well to figure that both laterals might be operating at the extreme end of the main line, which would be the worst condition of opera-

tion. Values of the fraction loss per 100 feet for 300 gpm in 4- and 5-inch pipe, taken from table 4, are 2.86 and 0.97 psi respectively. For 600 feet of line the total loss in the 4- and 5-inch lines would be 17.16 and 5.82 psi. If the operating pressure at the pump is assumed to be about 50 psi, the recommended allowable friction loss in the main line would be approximately 7.5 psi. Therefore, the loss in the 5-inch line would be less than the allowable amount, and a 5-inch line would be used.

This is one way of selecting mainline pipe size. An economic analysis should be made to check this selection.

Lateral pipeline size. With 30-foot spacing of sprinklers on the laterals there will be 22 sprinklers on each lateral, discharging approximately 6.75 gpm. Table 5 shows that for 30-foot spacing, 3-inch pipe will accommodate 21 to 24 sprinklers between 6 and 7 gpm. Therefore, 3-inch lateral lines would be selected.

To obtain the actual amount of friction loss in the lateral line with sprinklers, a factor can be applied to the friction loss in the same size pipe without sprinklers. Values of this factor are given in table 6.

In this example the factor for 22 sprinklers is 0.357. This number is then multiplied by the friction loss obtained from table 4 for the flow of 22 sprinklers: 22×6.75 gpm = 148.5 gpm in 660 feet of 3-inch line, which is 2.91 psi per 100 feet. The total lateral friction loss is, then, $2.91 \times \frac{660 \text{ ft.}}{100 \text{ ft.}} \times 0.357 = 6.85$ psi.

Horsepower required. The horsepower requirements are determined by the amount of water pumped, the total head or pressure, and the efficiency of the pump.

In this example the flow required is 297 gpm. The head requirements include the sprinkler pressure, friction loss for the main line laterals, and miscellaneous pipe fittings, and the pumping lift in the well. If the pumping lift for 297 gpm in the well is 52 feet, the total head would be as follows:

Sprinkler pressure	35.0 psi \times 2.31 = 81.0 feet
Main-line friction loss.....	5.82 psi \times 2.31 = 13.4 feet
Lateral friction loss	6.85 psi \times 2.31 = 15.8 feet
Miscellaneous friction loss.....	3.00 psi \times 2.31 = 6.9 feet
Pumping lift	52.0 feet
Total	169.1 feet

The theoretical water horsepower would be:

$$\text{hp} = \frac{297 \text{ gpm} \times 169.1 \text{ ft.}}{3,960} = 12.7$$

If a pump efficiency is assumed to be 70 per cent, the brake horsepower required is:

$$\text{brake hp} = \frac{12.7}{0.70} = 18.15$$

This would require a 20-hp electric motor.

Labor. The labor required to move laterals will depend upon several factors: type of system, frequency of move, number of irrigations per season, spacing of laterals, length of each pipe section, source of water supply, type of pump and drive unit, soil conditions, and type and height of crop.

Since there are many variables, it is reasonable to expect a wide range of labor requirements. Labor is seldom less than 0.5 man-hour per acre per irrigation, and in some cases it may go as high as 5 man-hours per acre per irrigation. An average figure for hand-moved systems is about 1¼ man-hours per acre per irrigation. Generally, orchard requirements are slightly higher, all other things being equal.

Fertilizer application

Some fertilizers can be applied by sprinkler systems, although certain ones present definite problems. Others should not be used in a sprinkler system. In general, use of the fertilizers depends on two conditions: 1) the compound must be relatively soluble in water or available in liquid form; 2) it should not be corrosive to the metals of the system, including the pump if the solution passes through the pump.

In California the fertilizers most commonly used are compounds containing nitrogen, phosphorus, and occasionally potassium. These compounds are available in different forms—solid, liquid, and gas. Most of the nitrogen and potassium compounds are soluble in water. The commonly used compounds of phosphorus are only slightly soluble. Those that are soluble enough to apply through sprinklers include phosphoric acid and ammonium phosphate, and these can be corrosive to metals.

Even though a chemically pure compound may dissolve readily, most commercial fertilizers contain some impurities. These may reduce solubility or leave residues that may clog the supply lines or sprinklers. The impurities in ammonium sulfate, for example, may amount to 4 to 6 per cent and sometimes as much as 10 per cent. When this fertilizer is injected into a system, there is also some possibility that the concentration of sulfuric acid may be great enough to cause corrosion.

Application of anhydrous ammonia (a compressed gas) and nitrogen solutions containing free ammonia through a sprinkler system is not recommended. Losses by diffusion into the air are excessive.

Preliminary tests with ammonia salts, such as ammonium, nitrate, sulfate, and

phosphate, indicate that losses of ammonia due to diffusion can be reduced by applying solutions at as high concentrations as possible without causing damage to the crop.² For a slightly alkaline water the initial ammonia concentrations should be 100 ppm or more. The most important factors influencing the loss are: the initial pH, the final pH following injection of the fertilizer, the buffering capacity of the water, and the residual acidity of the fertilizer. Water temperature is less important, although the loss is somewhat smaller at lower water temperatures.

A good procedure to follow in applying fertilizers through a sprinkler system involves three periods of time during each regular set of a lateral. During the first period, water is applied for a long enough time to wet the plant foliage and surface soil thoroughly. This will prevent the concentration of strong fertilizer solutions on dry leaves, which may cause injury.

During the second period the fertilizer is injected into the system. The actual time required will depend on the quantity of solution being injected, the length of pipeline, and, in the case of ammonia salts, the maintenance of a high enough concentration of the solution to minimize the evaporation loss.

The final period is essentially a flushing operation. Enough time should remain at the end of the fertilizer application period to: 1) rinse the system thoroughly, and 2) wash the fertilizer solution off the crop foliage.

These three periods are not of equal length. Actually, in an 11-hour setting the first two steps may take only about 10 per cent of the total time, but someone must

² "Ammonia loss from sprinkler jets," by D. W. Henderson, W. C. Bianchi, and L. D. Doneen in *Agricultural Engineering* 36(6): 398-399, June, 1955.

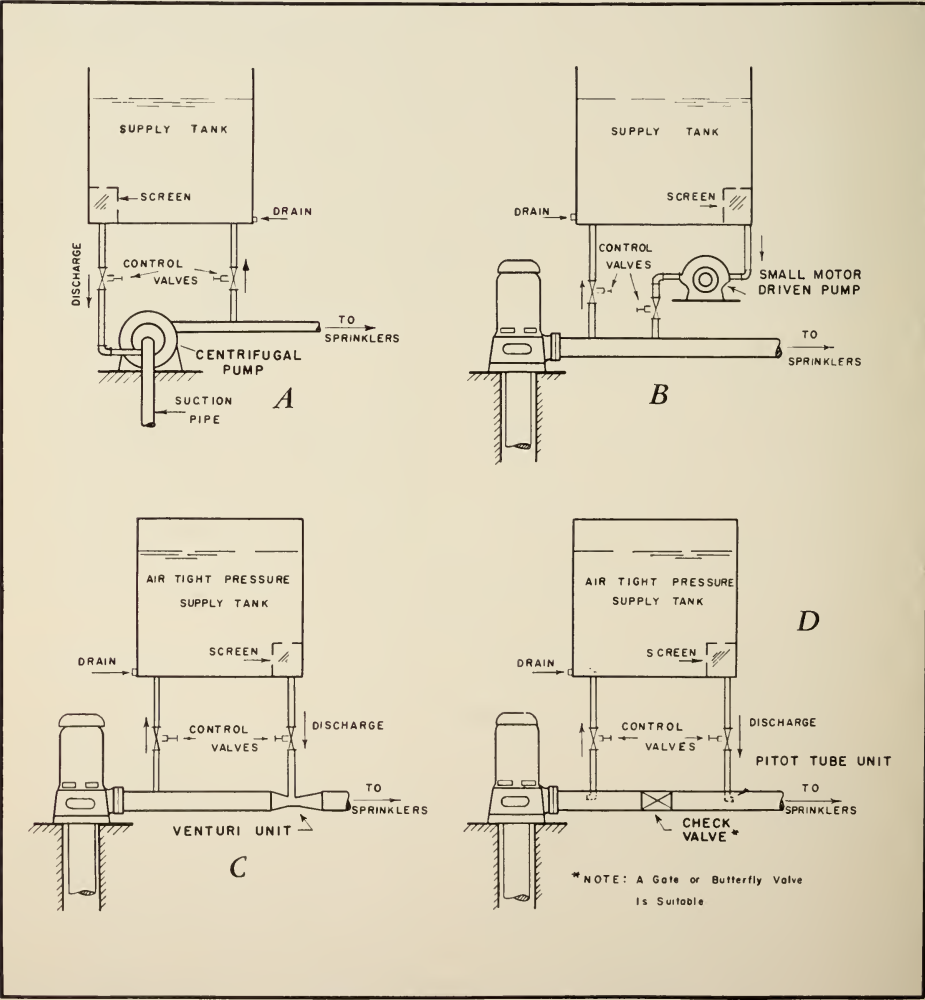
be present to start the fertilizer solution into the system sometime after the beginning of each set. This procedure should, however, help prolong the life of the system.

Methods of injection. There are several methods of injecting fertilizer solutions into a sprinkler system. A number of devices to aid in this operation are available commercially.

In one popular and practical method, suitable for a system involving a centrifugal pump, the injection is made through

a line connecting an open supply tank to a fitting on the suction side of the pump (Diagram A). The solution is drawn in by the reduced pressure in this pipe. Another hose or pipe connection can be made on the discharge side of the pump to facilitate filling the supply tank.

Occasionally a separate pump unit is used to pump the fertilizer solution from a supply tank into the sprinkler line (Diagram B). This pump must be able to deliver the solution into the line at greater pressure than that delivered by the irrigation pump.



Diagrams of the set-up for adding fertilizer in solution to a sprinkler-irrigation system.

Other methods make use of differential pressures for circulating water from the sprinkler line through the supply tank and back to the sprinkler line. One such device is a Venturi unit placed in the pipeline (Diagram C), another makes use of Pitot tubes (Diagram D).

Whatever method is used, the supply tank must be considered. It should be large enough to hold the proper amount of solution and still permit mixing if necessary. A noncorrosive screen on the outlet to the system is a good idea, as this will prevent large pieces of undissolved fertilizer from being carried into the system where it may clog a sprinkler. Also, a drain at the bottom to permit rinsing and emptying will help make the tank last longer. When connected to a pressure line, the tank should be designed to withstand the maximum anticipated operating pressure in the sprinkler line.

Corrosion of sprinkler systems

In general, aluminum is an excellent material for use in sprinkler systems because of its resistance to corrosion by many types of water and under most conditions. However, in a few scattered areas of California, corrosion of sprinkler systems still presents a problem. In some cases only minor damage has occurred, but in others, pipe and fittings have had to be replaced after one or two seasons' use.

Corrosion is a very complex phenomenon. In most cases the damage is attributed to electrolytic or galvanic processes. This means that a difference in electrical potential develops between the metal, or metals, of the pipe and its environment. In the case of a sprinkler pipe this difference may occur between dissimilar metals or between the pipe and the water or soil. As a result, small corrosion cells develop on the surface of the pipe, loss of metal occurs, and eventually small holes develop. Another source of corrosion is excess amounts of free carbon dioxide, which is present in some well waters.

If unusually severe or rapid corrosion occurs or is expected, the manufacturers of aluminum pipe suggest a treatment that will minimize this damage. This involves a mechanical and chemical cleaning to remove all products of corrosion, followed by a protective paint coating. The steps are as follows:

Thoroughly wire-brush the pipe. This is done with a tapered brush of fine steel wire, slightly larger than the pipe diameter, attached to a long-shaft extension, such as half-inch pipe. An electric drill of suitable size is used to rotate the shaft. All loose corrosion products should be removed by blowing or wiping.

Next, remove the remaining traces of corrosion products by chemical cleaning. This is done by immersing the pipe in an uninhibited phosphoric acid cleaner, such as Oakite 33 or 36, Dexoidine 526, or Kelite Process K. Follow the manufacturer's recommendations concerning the temperature and time of immersion. For large operations a dipping tank can be constructed by welding together halved sections of 55-gallon oil drums. If no tank is available, one end of the pipe can be plugged and the cleaner poured in the pipe. After cleaning, rinse the pipe thoroughly with fresh, clean water, and dry it completely.

The final step is to coat the pipe uniformly with a good-quality paint. Paints for use on aluminum should not be pigmented with lead or copper. Some paints that have been used are: Zincilate 300 and 410, Aluminum Metal and Masonry, Carbonzite, Zinc Chromate Primer, and Metal Etching Primer.

The paint can be applied by inclining the pipe at an angle of approximately 10 degrees from the horizontal and pouring in enough paint to cover the surface thoroughly as the pipe is slowly rotated. Inside spray equipment can also be used effectively. Average coverage should be about 500 square feet per gallon of paint.

In general, initial investment and cost of operation are lowest when a system is

planned for continuous use and the amount of water applied is just enough to satisfy peak requirements and cover field application losses. But whether a small system, operated more or less continuously, will be more economical than a larger one, operated only a few days for each irrigation, depends primarily upon the conditions on a particular farm. If a

system requires continuous attention, it may not be economical because the labor cost of operation may be very high.

A small portable system can sometimes be operated by moving the lines only once or twice a day (morning and evening). This can be a one-man job, leaving the farmer free to attend to other farm operations during the day.

INVESTMENT and OPERATING COSTS

Figuring annual cost

After obtaining the initial cost—the investment in equipment and installation—you will want to estimate the total annual cost of sprinkling. This includes fixed and operating costs. Taxes, insurance, interest on investment, and depreciation are the fixed costs. Operating costs include power, labor, maintenance, and repairs.

To determine the depreciation, the useful life and consequent annual depreciation rate for each item of the system should be figured separately. Other users, manufacturers, or dealers may be able to give you an estimate of the useful life of parts of the equipment. However, a period of 10 to 15 years is often used as a basis for depreciating the sprinkler system as a unit.

The annual costs of operation can be divided into two items: the power cost (including fuel or electricity and lubricating oil) and the labor cost for handling the system.

The original investment and annual cost will vary greatly from one system to another even within the same locality. Factors that cause the original investment to vary include: the source and location of the water supply; the size, shape, and arrangement of the area to be sprinkled; and the elaborateness of the system. Annual costs are influenced by cost of wa-

ter, fuel charges, crop requirements, number of irrigations, amount of water applied per irrigation, total amount of water applied, and the amount and cost of labor.

Only a few cost studies on sprinkler systems have been made. The results of some of the more recent studies conducted by County Agricultural Extension personnel are presented in table 7. Three examples were selected to represent typical systems of the areas. Included is a breakdown of the original investment and operating costs. In some cases complete data were not available. It should be pointed out that from the information obtained it is not possible to tell whether the best designed and operated system is being used in each case. Undoubtedly improvements could be made in some instances.

Wide variations in the original investment and in the fixed and operating costs will be noted. These reflect the differences in the acres irrigated, the size and type of system, the number of irrigations, and the amount of water applied during each irrigation. For example, compare systems 1 and 3 of the Tehama County study. System 1 irrigated 165 acres 26 times, applying 3.3 inches per irrigation. System 3 had approximately half this acreage, irrigated three more times, but applied only 1.5 inches per irrigation. The cost per acre of the two systems was

Table 7. Sprinkler Irrigation Costs

	Tehama County 1951 Forage crops			Ventura and San Diego counties 1951 Forage crops			Los Angeles Riverside, Orange counties 1948-49 Truck crops		
	System			System			System		
	1	2	3	1	2	3	1	2	3
Acres.....	165	50	81	62	70	22	65	170	39
Number of irrigations. . .	26	16	29	11	15	18	4	2	16
Inches per irrigation.....	3.3	3.3	1.5	3.7	3.0	2.5	4.4	4.8	1.6
Total inches per season..	87.0	53.0	45.0	41.0	44.5	45.0	17.5	9.6	36.0
Cost per acre									
Original investment:									
Well.....	\$ 4.85	\$ 39.70	\$ 44.50	.....	.....	.....	.....	.....	.....
Pump.....	23.00	32.40	24.00	.....	.....	.....	.....	.....	.....
Sprinkler system.....	50.90	79.60	55.60	\$108.00*	\$137.00*	\$74.00*	\$128.00*	\$52.00*	\$139.00*
Total.....	\$ 78.75	\$151.70	\$124.10	.....	.....	.....	.....	.....	.....
Annual irrigation costs:									
Fixed costs.....	\$ 8.45	\$ 12.02	\$ 11.79	\$ 11.35	\$ 15.30	\$ 8.45	12.70	5.65	13.50
Operating costs									
Power.....	7.53	9.79	10.03	20.20	38.70	19.70	10.70	6.35	23.40
Labor.....	10.91	8.26	17.35	16.00	23.20	12.40	4.80	4.50	21.60
Misc.....	.....	1.20	2.36	.....	.....	.....	.....	.....	.....
Total annual cost/acre	\$ 26.89	\$ 31.27	\$ 41.53	\$ 47.55	\$ 77.20	\$ 40.55	\$ 28.20	\$ 16.50	\$ 58.50

* Detailed breakdown not available; cost may include the pump and a well.

Table 7. Sprinkler Irrigation Costs (Continued)

	Butte County 1951 Almonds				Solano County 1952 Deciduous orchards				Ventura, San Bernardino, Orange counties 1948-49 Citrus		
	System				System				System		
	1	2	3		1	2	3		1	2	3
Acres.....	....†	....†	....†		....†	....†	....†		57	10	25
Number of irrigations...	3	2	3		2	2 and 3	3		13	7	10
Inches per irrigation.....	5.2	7.2	3.2		5.4	5.0	5.2		3.0	2.9	3.2
Total inches per season...	15.5	14.5	9.6		10.8	12.2	15.6		38.0	20.3	32.0
Cost per acre											
Original investment:											
Sprinkler system *	\$ 60.00	\$128.00	\$150.00		\$117.29	\$105.36	\$ 26.89		\$108.00	\$ 70.00	\$213.00
Annual irrigation costs:											
Fixed costs	11.08	18.42	22.75		15.91	15.58	7.26		15.50	6.50	27.10
Operating costs											
Power.....	3.67	6.07	5.14		5.38	11.58	6.01		29.45	49.05	51.70
Labor.....	2.70	1.74	6.00		2.91	4.94	3.94		39.50	12.20	26.40
Total annual cost/acre	\$ 17.45	\$ 26.23	\$ 33.89		\$ 24.20	\$ 32.10	\$ 17.21		\$ 84.45	\$ 67.75	\$105.20

* Detailed breakdown not available; cost may include the pump and a well.

† Unknown.

about the same—\$50.90 and \$55.60. The costs per acre of power, and particularly of labor, were higher for system 3. As a result, the total annual irrigation cost for system 3 is more than one and one-half times that of system 1.

Differences such as these are to be ex-

pected when comparing sprinkler-system costs because each farm has its own particular problems. To do the essential job of maintaining a steady water supply for plant growth involves many factors, and each farmer should consider all of them in determining what his costs will be.

REFERENCES

Should I Use Sprinklers for Irrigating Vegetable Crops?

P. A. Minges and L. J. Booher. Extension Service Leaflet.

Adjustable-length Irrigation Pipe Trailer.

M. O'Brien and L. J. Booher. Extension Service, Farm Irrigation Structures Leaflet.

Irrigation Pumps, Their Selection and Use.

C. N. Johnston. Calif. Agr. Exp. Sta. Circular 415.

In order that the information in our publications may be more intelligible it is sometimes necessary to use trade names of products or equipment rather than complicated descriptive or chemical identifications. In so doing it is unavoidable in some cases that similar products which are on the market under other trade names may not be cited. No endorsement of named products is intended nor is criticism implied of similar products which are not mentioned.

CONVENIENT EQUIVALENTS

These equivalents may be used for converting from one unit to another:

Area:

1 acre	= 43,560 square feet
	= 66 feet \times 660 feet
	= 33 feet \times 1,320 feet

Weight:

1 gallon weighs approximately 8.33 pounds
1 cubic foot weighs approximately 62.4 pounds

Volume:

1 gallon	= 231 cubic inches
1 cubic foot	= 1,728 cubic inches
	= 7.5 gallons
1 acre-inch	= 3,630 cubic feet
	= 27,154 gallons
	= $\frac{1}{12}$ acre-foot
1 acre-foot	= 43,560 cubic feet
	= 325,851 gallons
	= 12 acre-inches

Rates of flow:

1 cubic foot per second	= 450 gallons per minute
	= 7.5 gallons per second
	= 50 southern California miner's inches
	= 40 California statute miner's inches
	= 1 acre-inch per hour
	= 2 acre-feet per day (24 hours)
1 southern California miner's inch	= 9 gallons per minute
1 California statute miner's inch	= $11\frac{1}{4}$ gallons per minute

Volume from rates of flow:

1 cubic foot per second for 1 hour	= 3,600 cubic feet
	= approximately 1 acre-inch
1 cubic foot per second for 12 hours	= approximately 1 acre-foot
450 gallons per minute for 1 hour	= approximately 1 acre-inch

Pressure and Head:

1 pound per square inch	= 2.31 feet of water
1 foot of water	= 0.433 pound per square inch
1 atmosphere at sea level	= 14.7 pounds per square inch

Work and Power:

1 horsepower	= 550 foot pounds per second
	= 33,000 foot pounds per minute
	= 0.746 kilowatt
1 kilowatt	= 1.34 horsepower